PROCEEDINGS
OF THE
NATIONAL ACADEMY OF SCIENCES
Volume 3 MAY 15, 1917 Number 5

THE LAWS OF ELASTICO-VISCOUS FLOW

By A. A. Michelson
DEPARTMENT OF PHYSICS, UNIVERSITY OF CHICAGO
Read before the Academy, November 14, 1916

When a solid is subjected to a strain beyond the 'Elastic Limit,'* its behavior may be summarized as follows:

First: The application of the stress results in a rapid elastic yield, which if inertia be negligible is practically instantaneous. If the stress be now removed, the specimen returns to its former position.†

Second: This is followed by a slower yielding whose rate, if the stress is not too great, diminishes with time, and which ultimately attains a constant value which may be zero.

If the stress be now removed the specimen returns almost instantaneously to a point short of its original position, and then continues at a much slower rate and ultimately comes to rest at a point short of its original position.

If the stress is too great, the slow yield may increase until rupture occurs.‡

The following may be considered as a provisional attempt to formulate the behavior of substances under stress by the simplest expressions which have been found to satisfy all the essential requirements.

* The term 'elastic limit' is very vague and should be replaced by limits which may be characterized as follows: a. *The first limit* is that within which the specimen returns instantly to its original zero. Beyond this limit, if stress be instantly removed, the specimen promptly returns to a position short of its original one, which may be designated the 'new zero.' b. *The second limit* is that beyond which the specimen does not return to its original position or to the 'new zero,' even after a long time. c. *The third limit* is that value of the stress which produces rapid yielding or rupture.

† In many cases the time interval between application and release of stress cannot be made sufficiently short for complete instantaneous recovery.

‡ Rupture may occur in consequence of such slow yielding, or, it may be practically instantaneous. In the former case, the result is due to separation of the viscous coupling; in the second to the snapping of the spring.

The formulae which follow are in fact sufficiently general to include every case thus far examined, including materials of widely different properties, such as lead, tin, copper, aluminum, zinc, iron, steel, quartz, glass, calcite, limestone, slate, marble, wax, pitch, gelatine and rubber. It may, however, be expected that a more thorough investigation will require modification in the formulae which may be made to fit special cases with greater accuracy.

The type of strain selected for this investigation is the torsion of cylindrical rods, as this is the only strain in which the form remains unaltered. It is very probable that the laws governing this special type may be made to include other distortions such as extension, compression, bending, etc.

Very decided changes may be expected from the effects of temperature and pressure,* but these may be taken into account by an appropriate alteration in the value of the 'constants' which enter into the formulae.

The apparatus employed for the investigation consisted in a light pulley with radius of 8 cm. over which passed two cords, the ends of which carried scale pans for holding weights.

The specimen to be investigated had a diameter of 12 mm. at the ends while the intervening portion (75 mm. long) had a diameter of 4 mm. One end was clamped to the supporting frame and the other to the pulley which rests on a knife-edge in the axis.

The tests consisted in measuring the angular position of the pulley by a micrometer at intervals of one minute while under a constant torque.

Laws of Elastico-viscous Flow.—The behavior of any solid under stress may be considered as the resultant of four elements:

a. The elastic displacement,
b. The elastico-viscous displacement,
c. The viscous displacement,
d. The lost motion.

These will be considered in turn.

The Elastic Displacement.—This is characterized by being approxi-

* A preliminary investigation of the effect of hydrostatic pressure on elasticity and on viscosity was begun several years ago, which it was hoped would show results in conformity with those which maintain in the body of the earth—whose enormous pressure produces an increase in both rigidity and viscosity sufficient to make the body of the earth (which at its actual temperature under ordinary conditions would certainly be in a molten state) as solid as steel. This expectation has been partially realized for a number of materials, metallic and non-metallic; the results notwithstanding certain anomalies—traceable to the effects of previous history—showing a perceptible increase in rigidity and a very marked increase in viscosity even with the relatively small pressures obtainable in the laboratory.

mately proportional to the stress and independent of time.* A closer approximation is given by

$$S_1 = C_1 P e^{hP}$$

The Elastico-viscous Displacement.—This is manifested in a slow return when the stress is removed; and it is assumed that the same forces are brought into play during the direct motion.

This displacement is represented by the formula $S_2 = A_2(1-e^{-\alpha\sqrt{t}})$ where $A_2 = C_2 P e^{hP}$.

The Viscous Displacement.—Here the elastic force is absent or very small in comparison with the viscous resistance. The specimen does not return to zero even after a long time interval.† The viscous displacement is given by $S_3 = (Ft + F_0 t_0)^\rho - (F_0 t_0)^\rho$ in which $F = C_3 P e^{hP}$ and F_0 the corresponding value, when P has the value P_0 during the time, t_0.

For a specimen which has not been subjected to previous strain the formula reduces to $S_3 = (Ft)^\rho$. Experiment gives $\rho = \frac{1}{2}$ approximately, until the specimen is near the rupture point when ρ approaches the value unity.

The Lost Motion.—If the stress be applied for a short time (even a small fraction of a second) the specimen does not return to the original zero. The difference between the original and the new zero is the lost motion, L.

It seems probable that the lost motion may be considered as a function of t such as t^r, where r is very small (less than 0.02 for zinc).

If this be considered as part of the viscous term

$$S_3 = A_3 f(t)$$

then the total viscous yield may be represented by

$$S_3 = A_3[f(t) + Ct^r]$$

(If the actual stress is between the limits 0 and P_0, $C = 0$)

The Return.—If after a time, t_0 the displacement has reached the value, S, and the stress is released, the specimen promptly returns to a displacement short of zero, and continues much more slowly in the same direction.

If the elastico-viscous displacement at the time, t_0 is given by

$$S_2 = A_2(1 - e^{-\alpha\sqrt{t_0}})$$

* Doubtless there is some viscous resistance to this displacement, but it is very small.

† In some cases it may be made to return to the original position by heating, or by alternation (alternate positive and negative diminishing stresses).

the corresponding return displacement at the time, t, counted from the instant of release, will be

$$R_2 = A_2 e^{-\alpha\sqrt{t}}(1 - e^{-\alpha\sqrt{t_0}})$$

To account for the viscous term assume*

$$F = \epsilon S^n \dot{S}$$

whence

$$S_3 = \left[\frac{1}{\rho\epsilon}\int F\,dt\right]^\rho, \qquad \rho = \frac{1}{n+1}$$

If F = constant, and F_0 the constant value of F during the preceding stress during the time, t_0,

$$S_3 = \frac{1}{\rho\epsilon}[(Ft + F_0 t_0)^\rho - (F_0 t_0)^\rho]$$

counting from the actual zero.

As shown by the formula, if the previous strain be considerable the new strain is relatively small. This strengthening by previous strain is one of the striking features of the behavior of every substance which exhibits viscous yield.

If, in this expression, F represents the actual stress, it assumes that the viscous force is proportional to the velocity, which is true for fluids; but for 'solid friction,' the force is independent of the velocity.

It may be assumed in the present case of internal viscosity of solids that the actual law may be between these two extremes, e.g.

$$P = a\,(\dot{S})^K \qquad \text{in which } K < 1$$

This would give P^n instead of P, or, in better agreement with experiment,

$$F' = PCe^{hP}$$

The elastico-viscous term is readily obtained by making the viscosity coefficient a function of the time.

Thus, if the restoring force be represented by a s and the viscous resistance† by $\epsilon t^m \dot{S}$, the integration gives $S_2 = S_0(1 - e^{-\frac{\alpha}{r}t^r})$ where $\alpha = \frac{a}{\epsilon}$ and‡ $r = -m + 1$.

* Experiment gives $\rho = \frac{1}{2}$, (0.3 to 0.6) which makes $n = 1$. The usual assumption, $n = 0$ gives $\rho = 1$.

† The assumptions in both viscous and elastico-viscous hypotheses made the viscosity coefficient (that is the coefficient of $\dot{S}$) zero at the beginning of the motion and infinite at $t = \infty$ which is, of course, inadmissible. Instead of S^n and t^m we might substitute $(\beta + S^n)/(b + S^n)$ and $(\gamma + t^m)/(c + t^m)$ in which β/b and γ/c are very small; but the resulting equations are far less simple and are not appreciably more accurate in expressing the results than those here given.

‡ The usual assumption, $m = 0$, gives $r = 1$.

To determine the effect of temperature, the behavior of zinc, glass, ebonite, pitch and wax was studied. The results, together with the preceding may be summarized in the following formulae:*

$$S = A_1 + A_2 T_2 + A_3 T_3,$$

$$A_1 = C_1 P e^{hP}, \qquad C_1 = E_0 + E_1 e^{K_1\theta},$$
$$A_2 = C_2 P e^{hP}, \qquad C_2 = E_2 e^{K_2\theta},$$
$$A_3 = C_3 P e^{hP}, \qquad C_3 = E_3 \theta (T - \theta)^{-1},$$
$$T_2 = 1 - e^{-\alpha\sqrt{t}}, \qquad h = b\theta,$$

$$T_3 = \left(t + \frac{A_0}{A_3} t_0\right)^{\rho} - \left(\frac{A_0}{A_3} t_0\right)^{\rho}, \quad \rho = \rho_0 + \frac{a}{1 + \left(\frac{\pi}{P\theta}\right)^m};$$

S = displacement (twist), P = applied torque,
t = time, t_0 = duration of previous stress,
θ = temperature, T = melting point,
h, k, α, E, P_0, a, b, m, π, constants.

* Instead of this series coupling, the following may be substituted: The unit consists of four elements: (1), (2) and (3) are in viscous contact with (4). (1) and (2) are in elastic coupling; and finally (3) of this unit is connected with (1) of the next following unit by an elastic coupling. The resulting formulae, however, are not essentially different from those here given.

A NEW EQUATION OF CONTINUITY

By Frederick G. Keyes

RESEARCH LABORATORY OF PHYSICAL CHEMISTRY, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Communicated by A. A. Noyes, February 28, 1917

This paper presents a pressure, volume, temperature relation which has been carefully compared with the greater part of the available experimental data during the past ten years. The equation, valid when only one type of molecule is present, is

$$p = \frac{R}{v - \delta} T - \frac{a}{(v - l)^2} \qquad (1)$$

where $\log \delta = \log \beta - \alpha/v$, and β, α, a, and b are constants; R is the universal gas constant.

The equation is based on considerations resulting from the inferences regarding atomic structure, obtained since the discovery of the negative electron. The model atom consists of a positive central portion about

which electrons are revolving. The negative electrons are assumed to possess a charge in the aggregate equal and opposite to the positive central charge. This model atom is essentially the atom discussed by Nicholson and Bohr.

Imagine an assemblage of such model atoms contained within an envelope and subject to their mutual attractive forces. The revolving electrons of a given atom generate a magnetic field and for convenience, therefore, the revolving electrons may be conceived as circles of current about the positive central portion of the atom. The positive central portion of one such atom repels the positive charge of another atom in a manner varying inversely as the square of the distance, and similarly the negative charges repel as r^{-2}. The negative charges attract the positive also according to r^{-2}; but since, if all of the atoms were suddenly fixed in position their average distances apart would be equal, it may be assumed that the attractions and repulsions of the positive and negative charges mutually cancel. The potential due to the fields of the revolving electrons however do not cancel and therefore on the whole the resultant attraction in the assemblage of particles varies approximately as r^{-4}.

The attempt to calculate the complete expression for the force between two such model atoms is difficult and will require a more detailed knowledge of the atom. Sufficient is known, however, to make it certain that the attraction increases slightly more rapidly than r^{-4}.

An envelope of volume v and containing n particles would provide a space for the habitation of each particle on the average equal to v/n, so that the distance apart of the molecules, if a is the radius of the spherical envelope, would be equal to $\sigma = a(4\pi/3n)^{\frac{1}{3}}$. Therefore the potential energy would be proportional to $\frac{1}{2}\ \Sigma\Sigma\sigma^{-4}$ or equal to h/v where h is a suitable constant. The attraction then directed toward the center, would be per unit of surface identical in form to van der Waals' cohesive pressure a/v^2. Now if the attractive force really increases slightly more rapidly than r^{-4} as appears to be really the case, it is easily perceived that a/v^2 would only be valid at very large volumes. A simple device to correct the expression is to assume that Φ; the cohesive pressure, may be represented by $a/(v-l)^2$, where l is a small constant which will of course make Φ increase more rapidly with diminution of volume than a/v^2 in the ratio of $v^2/(v-l)^2$.

The truth of the cohesive pressure expression $\Phi = a/(v-l)^2$ can be determined only by experiment since a rigorously complete solution for the attraction of an assemblage of the model atoms appears to be impracticable. If then the volume function for Φ given, is in agreement

with experiment and the sign of l comes out positive and not negative, as there is good reason to suppose it should, increased faith in the validity of the fundamental thought will have been established.

The term $(v-b)$ of van der Waals has given rise to much discussion. It now appears that a rigorous application of van der Waals' mode of thought really leads to a different expression for the 'volume correction.' It is, however, $(v-b)$ which seems to be the corrrect form as judged by comparison with experiment. With potential forces existing between the particles, it is difficult to see how collisions occur in the sense of the classical kinetic theory, at any rate within the mass of the gas. Indeed for an assemblage of particles such as here imagined a collision, as conceived by the older theory would not occur in general, except possibly at the boundary. It would, however, still be necessary to take account of the finite size of the atoms or rather more likely a certain space the center of which was occupied by an atom. In the case of a monatomic gas this volume would be fixed and the b of van der Waals therefore a constant. The equation of state for a monatomic gas at those volumes and temperatures where association is excluded would accordingly be

$$p = \frac{R}{v-\beta}T - \frac{a}{(v-l)^2} \qquad (2)$$

where β, a, l are constants and R is the absolute gas constant defined by $R = pv/T$, the equation of a perfect gas.

When two of the model atoms are united to form a diatomic molecule an effect comes into play which is absent so long as monatomic particles are alone considered. A diatomic molecule is assumed to be held together by forces due to the positive and negative charges and the magnetic effect of the field due to the rotating electrons. The distance apart of these diatomic molecules in general will be large compared to the distance separating the two atoms forming the di-atom; but in an assemblage of these di-atoms, the field due to the assemblage must react to vary the distance separating the two atoms of a diatomic molecule. This would be inferred from the fact that for a magnetic shell in a magnetic field the reaction is always such as to bring about a decrease in the mutual potential energy. This decrease in the molecular case under consideration would result in a shortening of the distance between the two atoms of the di-atom or a decrease in its apparent volume as the strength of the field due to the surrounding di-atoms increased. It appears at present an impossible task to calculate exactly the apparent volume corresponding to van der Waals' b from such a physical picture.

The original mode of guessing the form of function is accordingly given.

The value sought, denoted by δ, would be a function of the volume alone and such a function that at infinite volumes it becomes constant, since when large distances separate the di-atoms the effect of the field due to the surrounding molecules would be negligible. The value of δ for $v = \infty$ let it be assumed then is β, a constant. The rate of change of δ for changes in volume would presumably be a function of the field due to the assemblage of particles and the value of δ, since the effect is due to the mutual action of the forces holding the di-atoms together and the external field due to the diatoms conjointly. This may be expressed by writing $d\delta/dv = f(\delta F)$, where F is the force. Now the simplest assumption under the circumstances is to assume that $d\delta/dv = k\delta F$ where k is a constant. The value of F taken per unit of area is approximately a/v^2 and the primitive of the equation becomes then, $\log \delta = \log \beta - a/v$ where $ka = \alpha$ another constant, and β is of course the limiting value which δ assumes when v is infinite. The equation for a diatomic assemblage of particles becomes then equation (1).

The equation (1) arrived at by such crude methods has been found to accord with the facts in a surprisingly exact manner, but in the present paper I will exhibit the evidence which has to do with the gist of the whole argument underlying the deduction of equations one and two. A later paper will present a discussion of the equation from a more general point of view including a comparison with all the available experiment data for various substances. It accordingly suffices for the present purpose to point out that the whole thought is tested uniquely by comparing a diatomic system with a monatomic system. The value of δ for the monatomic substance reduces to the constant β independent of the volume while δ becomes a volume function when the system consists of diatomic particles alone.

Recently sufficient data have appeared for argon which enables the test to be applied, while the diatomic system nitrogen will serve to test the functional form of δ. The triatomic molecule carbon dioxide appears to follow the same functional form for both gas and liquid phases. It should be emphasized that only those regions are available as legitimate for comparison purposes in which one order of molecule is present. That is to say, there must be no doubling of the argon atoms to form diatoms or association of the nitrogen molecules within the region of experimental data where comparisons are made. Such regions are fortunately a part of the experimental data contained in the literature.

It is noted that when the volume is held constant equations one and two state that the pressure will increase linearly with the temperature.

This fact was observed and discussed by Ramsay and Young for ether and carbon dioxide. Amagat thought, from an examination of his own data, that the 'law' was nearly exact in the case of many substances, certainly not true, however, in the case of the alcohols and water. Unfortunately it is necessary to have very accurate pressure measurements, to test the rule and moreover the measurements have always been made along isotherms instead of along isobars. This makes it necessary to obtain the constant volume data by graphical means with the liability of introducing a trend into the experimental data. It is comparatively easy to measure temperatures and pressures, but volume measurements under pressure are extremely difficult. Every substance which may be used to serve as a container for the experimental substance expands with temperature and pressure increase and the expansion may be moreover a complicated function of the time.

There can scarcely be any doubt that the high pressure gauge used by Amagat for the measurements above 1000 atm. was more in error than his low pressure gauge. The values of pv for nitrogen were plotted accordingly for the several temperatures from 0° to 200°, with v as one coordinate in the region up to 1000 atm. Values of pv were read off at the different temperatures for various values of the volume thus yielding material for calculating the constant volume, pressures, and temperatures. These values were laid off on coordinate paper and the best straight line passed through the data. The equations of the several straight lines was corrected subsequently by calculating the deviations and constructing an additional graph by means of which a deviation equation could be evaluated and also any trend in the deviations detected.

The equations obtained were all of the form, $p = [\Psi T - \Phi]$, and by comparison with equation (1) $\Psi = R/(v-\delta)$ and $\Phi = a/(v-l)^2$ whence $\delta = v - R/\Psi$. The δ values may be treated best by using log δ and $1/v$ as the coordinates of the graph since it is propsed to test the functional form $\delta = \beta e^{-\alpha/v}$. The Φ values were tested by writing $v = \sqrt{a}/\sqrt{\Phi} + l$. It is seen that v should be plotted with $1/\sqrt{\Phi}$ as abscissae. The graph for nitrogen is given in figure one and for argon in figure two. It should be stated that the data given by Amagat above 1000 atm. give values of log δ which join on to the values in figure two, but begin to differ slightly in trend as the pressure becomes greater. In fact a straight line may be passed through the 1-1000 atm. series and the 1000–3000 atm. series with the lines intersecting at about 1000 atm. The effect is due undoubtedly to the inaccuracy of the high pressure gauge.

The graphs show the functional form of δ as related to volume changes is very accurately satisfied, while argon shows no trend. In the graph

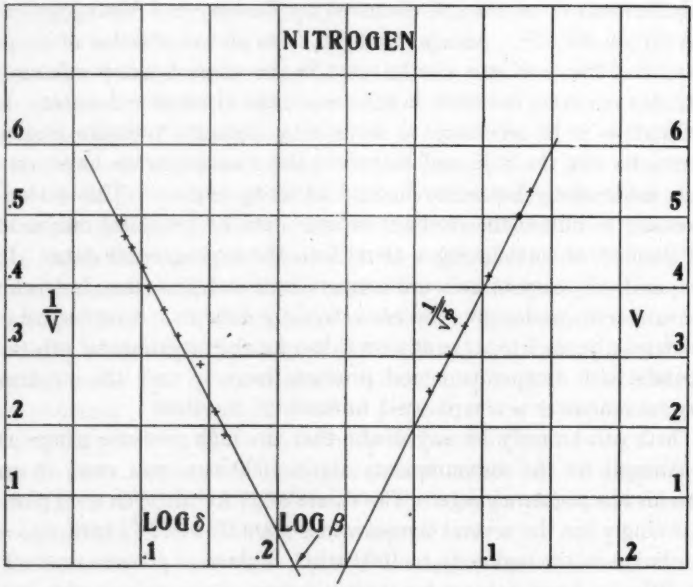

NITROGEN
.6
.5
.4
.3
.2
.1
1/V
LOG δ
.1
.2
LOG β
.1
.2
V
6
5
4
3
2
1

FIG. 1

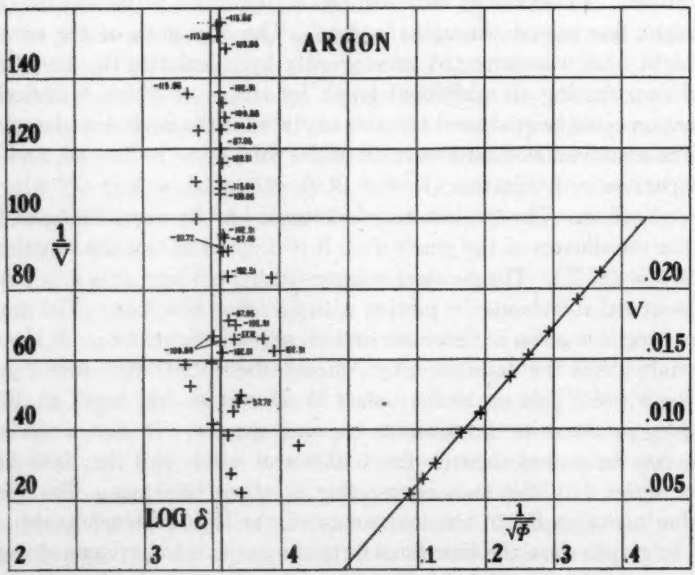

ARGON
140
120
100
80
60
40
20
2
1/V
LOG δ
3
4
.1
.2
.3
.4
1/√Φ
V
.020
.015
.010
.005

FIG. 2

TABLE 1

NITROGEN EQUATION OF STATE

v	p, $T=\phi$	p, 16.03°	p, 99.45°	p, 199.5°
5.354	149.8	161.8	225.4	299.7K
	150.0	162.0	225.0	299 A
4.150	199.8	217.2	306.6	414.0
	200.0	217.0	307.0	414.0
3.460	250.4	273.1	390.3	531.3
	250.0	273.0	392.0	530.0
3.024	299.7	327.6	472.4	646.4
	300.0	328.0	474.0	644.0
2.729	347.7	381.1	552.9	759.5
	350.0	383.0	556.0	758.0
2.511	396.0	434.4	632.8	870.8
	400.0	439.0	637.0	869.0

The volume of 1 gram as determined by experiment is 799.1. This volume substituted in the equation of state gives 1.0004 instead of 1.0000.

$$p = \frac{2.9139}{v-\delta}T - \frac{1587.2}{(v-0.007)^3}$$

$$\log_{10}\delta = 0.22001 - \frac{0.2839}{v}$$

TABLE 2

COMPARISON OF CALCULATED PRESSURES WITH PRESSURES GIVEN BY CROMMELIN FOR ARGON

TEMPERATURE	p_{cal}	p_{obs}	v	TEMPERATURE	p_{cal}	p_{obs}	v	TEMPERATURE	p_{cal}	p_{obs}	v
+20.39	61.932	61.741	0.016876					−119.2	37.753	37.641	0.010327
0°	31.478	31.572	0.030958	−113.8	42.692	42.682	0.009374		38.219	37.923	0.0101150
0°	36.671	36.61	0.026467		47.616	47.655	0.0077421		43.304	43.006	0.008002
−57.72	34.994	35.127	0.020782		52.074	51.752	0.006548		46.189	46.082	0.0069582
	45.876	46.209	0.015397		52.566	52.188	0.006435		47.95	47.272	0.0063954
	61.987	62.079	0.011026								
−87.05	33.231	33.296	0.017912								
	40.948	41.094	0.014003	−115.86	41.932	41.908	0.009257				
	51.431	51.533	0.010568		50.710	50.324	0.006446				
	61.822	61.830	0.008345		55.13	53.204	0.0055576				
−102.51	28.150	28.840	0.019037		55.83	57.493	0.0054536	−120.24	37.801	37.836	0.010083
	32.375	32.394	0.016070						41.566	41.668	0.0084389
	35.552	35.784	0.014294						44.346	44.510	0.0073363
	40.808	40.976	0.011916	−116.62	37.171	37.250	0.011042				
	45.000	45.088	0.010438		41.811	41.943	0.009075				
	51.323	51.398	0.0086296		46.164	46.496	0.0074801				
	56.996	56.882	0.007372		50.45	50.259	0.006261	−121.21	37.588	37.465	0.0099676
	63.262	62.239	0.0063285						41.848	41.932	0.0080740
−109.88	31.532	31.515	0.015351						45.266	45.282	0.0067138
	32.051	31.929	0.015031								
	49.402	49.515	0.007964								
	54.475	54.250	0.006742								

of the latter substance the logarithm of δ was plotted with the density in order to bring out more clearly the relation of the various δ values to the density although an inspection of the tabulated values show that δ is constant. It might be added that helium, while the data are less extensive, gives identically the same result as does argon.

In tables 1 and 2 will be found the comparisons of the pressures calculated for the volumes and temperatures as given by Amagat for nitrogen and Crommelin for argon. The nitrogen pressures calculated show about as good an agreement throughout with the observed pressures as could be expected.

THE CLASSIFICATION OF VASCULAR PLANTS

By Edward W. Berry

GEOLOGICAL LABORATORY, JOHNS HOPKINS UNIVERSITY

Communicated by W. Trelease, February 14, 1917

A scientific knowledge of plants or other natural objects consists to a very considerable extent in a knowledge of their mutual (phylogenetic) relations, hence the necessity of a Taxonomy that will consistently express filiation, which is only another way of stating that it should be phylogenetic. Science does not consist merely of names, but it cannot very well progress without a terminology, and not until this terminology becomes an expression of evolution can it become consistent and itself scientific.

Botanists have rather effectually grappled with this problem in the case of the lower plants, but the classification of the so-called vascular plants remains largely as an inheritance from the study of the end products of their evolution, namely a study of the existing vascular plants, with but slight consideration of the recent progress of paleobotanical investigation.

The not so very long obsolete practice of considering the Angiosperms and the Gymnosperms as subclasses of the class Exogens was a no more pernicious mask of their true relations than the extant usage which considers vascular plants as separable into two great phyla—the Pteridophyta or Sporophyta and the Spermophyta. With the subdivisions of these two groups the present situation is equally inexpressive of our present state of knowledge. To the paleobotanist the Angiosperms and the Gymnosperms are obviously not groups of the same order, the latter including several groups of comparable rank with the Angiosperms as a whole, and extending over a period of time expressed by the ratio of 21 for gymnosperms to 6 for angiosperms.

Furthermore can any characters be mentioned which in the light of paleobotanical knowledge and evolutionary theory are more illogical as the basis for the characterization of great groups than siphonogamy, or the number of cotyledons, or the great stress that is laid upon the morphology of flower parts in the classification of the socalled flowering plants.

The attempt to force the vegetation that clothed the earth five or ten, or fifteen millions of years ago into the taxonomic bounds formulated for the flora of a single geological period, namely—the Present, suggests the petrified asters (Sphenophyllum) which Lehmann described from the Carboniferous, or the cacti, galiums and euphorbias which Lindley once described from the English Coal Measures.

During the long ages of the Paleozoic there were at least four dominant major groups of land plants and a fifth should probably be added, since while the true ferns were not as numerous as was once supposed, the other groups show more or less evidence of having had ferns for ancestors. These other groups that were dominant in the Paleozoic are those of the seed ferns, the Lepidodendrons (and their allies), the Calamites (and their allies) and the Cordaites (and their allies). What can be said of a practice which unites in a single order such complex arborescent quasi seed plants as some of the lepidodendrons and existing club mosses separated by a time interval of many millions of years and by an almost equally great structural gap?

During the Mesozoic the dominant plants were the ferns, cycad-like plants, conifers and ginkgoes, all of which underwent adaptive radiations on all of the continents and which should form the basis for a dozen natural orders instead of but four, in fact Nathorst has already proposed that the cycad-like plants shall constitute a separate phylum—the Cycadophyta.

The proposals that follow were formulated in 1910 and have been tested in university and research work during the interval that has elapsed. They were used in an article on Paleobotany for the new International Encyclopedia (1915) and are put forward in a somewhat categorical manner at the present time as a summary of the present status of paleobotanical knowledge and as an invitation for comments from competent critics.

Phylum **Angiospermophyta** (ἀγγεῖον, a receptacle). Berry, 1915 (Anthophyta).

Phylum **Coniferophyta.** Coulter, 1912, Including the Gnetales.
Coniferales.
Araucariales.
Taxales*
Ginkgoales*
Cordaitales.

Phylum **Cycadophyta.** Nathorst, 1902.

Megaphyllous; leaves compound; stems phyllosiphonic; with primary roots; ciliated sperms. Gymnospermic and strobiloid. Including Cycadales, Williamson iales and Cycadeoidales (Benettitales).

Phylum **Pteridospermophyta.** Ward, 1904. (Cycadofilices of Potonié, 1902).

Megaphyllous; phyllosiphonic; spermophytic, ♂ and ♀ sporophylls little differentiated from the vegetative foliage; gymnospermic but never strobiloid; filicinean in form and habit and much of their vascular anatomy. Including Cladoxylaceae, Lyginodendraceae, Medullosaceae, Cycadoxylaceae, Protopityaceae and incertae sedis including Aneimites, Gigantopteris, Glossopteris, etc.

Phylum **Lepidophyta** (λεπίς, ἴδος, a scale). Berry, 1915.

Microphyllous; cladosiphonic, with exarch protostele; homosporous, heterosporous and quasi spermophytic. Prevailingly strobiloid.

Lycopodiales { Lycopodiaceae / Selaginellaceae
Isoetales
Psilotales†
Lepidodendrales { Bothrodendraceae / Lepidodendraceae / Sigillariaceae

Phylum **Arthrophyta** (ἄρθρον, a joint). Berry, 1915‡

Stems articulated at the nodes, ribbed. Leaves verticillate, dichotomously compound in the Pseudoborniales and the Protocalamariaceae, palmately laciniate in some Sphenophyllales; pro-

* There is a question whether these two groups with possibly the Cordaitales should not be united as an independent phylum intermediate between the Coniferophyta and the Cycadophyta.

† The Lepidophyta correspond to the Lycopsida of Scott except that he refers the Psilotales to his Sphenopsida (Scott, 1909).

‡ Nearly equivalent to the Articulatae of Lignier and the Sphenopsida of Scott.

gressively reduced during the history of the phylum. Sporangiophoric and strobiloid. Homosporous and heterosporous.

Class Sphenophyllae-Sphenophyllales

Class Calamariae
- Pseudoborniales (Nathorst, 1902)
- Calamariales
  - Calamariaceae
  - Protocalamariaceae (Potonie, 1899)
- Equisetales

Phylum **Pteridophyta** (emended to correspond to the Filicales). Berry, 1915.

Megaphyllous; phyllosiphonic; fructifications on but little modified foliage leaves, never strobiloid; prevailingly homosporous. Heterosporic and quasi spermophytic in certain highly specialized Paleozoic lines, and in existing Hydropterales.

Class 1. Coenopteridae (κοινός, common or general, in allusion to their generalized characters). Seward, 1910*

Class 2. (?) Eusporangiatae
- Ophioglossales
- Marattiales
- Psaronius (Pecopteris), etc.

Class 3. (?) Leptosporangiatae, or Eufilices†
- Osmundales
- Gleicheniales (?)
- Matoniales (?)
- Polypodiales, including Hymenophllaceae, Schizaeaceae, Cyatheaceae, Parkeriaceae, Polypodiaceae.

Class 4. Hydropteridae
- Hydropterales
- Sagenopterales‡

* The Inversicatenales of Bertrand (1909) and the Primofilices of Arber (1906).

† Probably has additional fossil representatives.

‡ The subdivisions of this class are tentative.

DISPLACEMENT INTERFEROMETRY IN CONNECTION WITH U-TUBES

By C. Barus

DEPARTMENT OF PHYSICS, BROWN UNIVERSITY

Communicated, March 7, 1917

1. *Introduction.*—A variety of constants in physics may be found from the relative heights of two communicating columns of liquid. This is for instance the case in the classical experiment of Dulong and Petit on the thermal expansion of liquids. Again if one of the tubes is subject to a special force acting in the direction of its axis, this force in its bearing on the liquid may be evaluated from the resulting difference of heads of the columns. Thus one tube may be surrounded by a magnetizing helix and the effect of the axial magnetic field on the liquid in question (i.e., the susceptibility) found from the displacement of its surface by the presence and absence of the field; etc. It seemed to me worth while therefore to test whether it would be possible to measure small displacements of this kind by passing the two component beams of a displacement interferometer axially *through* the two columns respectively, and to measure the differential effects in question in terms of the resulting displacements of fringes.

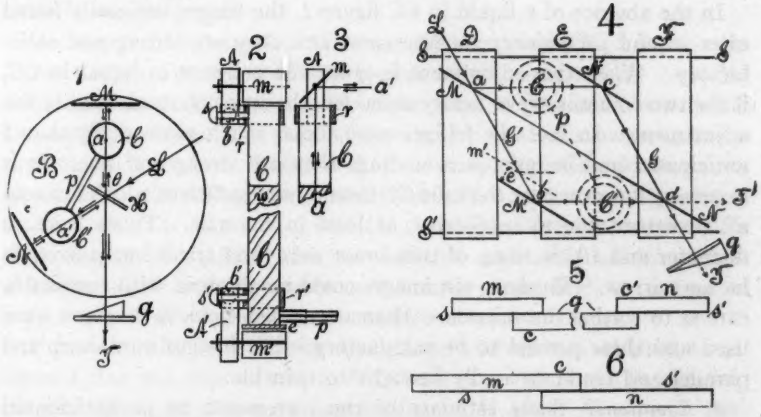
2. *Apparatus.*—The interferometer used was of the same form as that before described (these PROCEEDINGS, 3, 1917, 117), B in figure 1 being a heavy iron block, one foot in diameter and 1.5 inches thick, on which the mirrors M, N (the latter and preferably both on micrometers) are securely mounted with the usual direct rough and elastic fine adjustment for horizontal and vertical axes. A beam of parallel white rays L arrives from a collimator (not shown) and impinges on the half silver plate H, to be reflected and transmitted at a convenient angle θ (about 60°), thus furnishing the two component beams which are to traverse the limbs of the U-tube.

The vertical columns of this tube are shown at C and C' (with accessory mirrors removed) and they are joined to the capillary tube p near the bottom of C and C'. Details will be given in connection with figures 2 and 3.

The ray HM strikes a mirror symmetrically at 45° to the vertical below C, is thence reflected upward along the axis a striking another mirror above also symmetrically at 45° and parallel to the former, whence it is reflected to the opaque mirror M. The latter reflects the ray normally back so that it retraces its path as far as H, by which plate it is now transmitted to be observed by the telescope at T. Sim-

ilarly the transmitted component ray HN is guided by suitable reflectors at 45°, so as to take the path $Ha'Na'HT$, thus passing axially (a') through the tube C'.

It is necessary that the U-tube CpC' be mounted independently of the block B on suitable bracket or arm attached to the pier. Otherwise any manipulation at N will disturb the surfaces of water in C and C'. Ordinary clamps admit of raising or lowering or rotating CC' satisfactorily, always providing that it shall not touch B. The telescope at T is also mounted apart from B on the table below. The direct vision prism grating g is placed immediately in front of the objective and swivelled (as described, loc. cit.) so that either the white slit images or their spectra may be seen in the field of view, according as g is rotated aside or is in place.



In figure 2 a front sectional elevation of one of the shanks of the U-tube is given with all appurtenances, and a similar sectional elevation at right angles to the former is added in figure 3 for the top of the tube. In figure 2 the mirrors m' and m are on horizontal axes and the component ray coming from behind the diagram strikes m' below, is reflected axially upward through CC, impinging on the mirror m (also on a horizontal axis) whence it is reflected horizontally toward the front of the diagram. The ray a and mirror m are given more clearly in figure 3. The lateral capillary tube appears at p and the tube C is closed below with a plate of glass e, cemented in place.

To mount the mirrors m, m', snugly fitting rings r and r' encircle the tube C near its top and bottom and can be fixed by the set screws s and s'. In virtue of these rings the mirrors m, m', may be rotated at pleasure around the vertical axis a of CC. The horizontal axis of the

mirrors m, m', rotates at pleasure in the vertical arms A, A' of square brass tube. A, A' in turn may be slightly swivelled about the horizontal axis b, b', in a rigid lateral projection of the rings r, r'. Thus m, m' are capable of rotation around 3 axes normal to each other, and adequately clamped in any position.

The component ray HN may be adjusted to the center of the lower mirror m' by placing the collimator L and then guided axially by $m'mN$ as described each being adjustable. The component ray HM may be similarly adjusted to the center of the lower mirror m' (at 45°) by (slightly) rotating the half silver plate, H (on horizontal and vertical axes) and then guided axially by $m'mM$. As a whole the adjustment is difficult, though it need not be much refined. Clear white slit images in the telescope T are an adequate criterion.

In the absence of a liquid in CC figure 2, the fringes are easily found after careful preliminary measurement and they are strong and satisfactory. When this adjustment is given the presence of liquid in CC, if the two columns are of nearly equal length, does not much modify the adjustment. In fact the fringes were found much more easily than I anticipated and in quiet surroundings they are strong and fine. It is necessary however that the tube CC should be of sufficient width to avoid all curvature due to capillarity, at least in the axis. Tubes 2 cm. in diameter and 10 cm. long of thin brass were first tried, but proved to be too narrow. No sharp slit images could be obtained with reasonable care as to setting the mirrors. Thereafter tubes 4 cm. in diameter were used and these proved to be satisfactory. Slit images were sharp and parallel and could be easily brought to coincide.

3. *Equations.*—Some estimate of the increments to be anticipated may be given here, and expressed in terms of the Dulong-Petit experiment. If α is the mean coefficient of expansion of water at the temperature in question and ΔH the increment of the head H corresponding to the temperature difference Δt between the columns

$$\Delta H = \alpha H \Delta t \tag{1}$$

Again if ΔN corresponding to ΔH is the displacement of center of ellipses at the wave length λ and μ the index of refraction of water, so that $\mu = A + B/\lambda^2$, nearly,

$$\Delta H = \frac{\Delta n}{\mu - 1 + 2B/\lambda^2} \tag{2}$$

Hence Δt may be computed as

$$\Delta t = \frac{\Delta n}{(\mu - 1 + 2B/\lambda^2)\,\alpha H} \tag{3}$$

Since the value of ΔN is within 10^{-4} cm. and $H = 10$ cm. in the above apparatus, we may further write at mean temperatures (25°) $\alpha = 2.5 \times 10^{-4}$; $\mu = 1.333$; $B = 10^{-11} \times 3.1$, $2B/\lambda^2 = 0.018$ at the D line. Thus $\mu - 1 + 2B/\lambda^2 = .351$ and $\Delta t = 10^{-4}/3.51 \times 2.5 \times 10^{-4} \times 10 = 0.114°$. In other words in case of tubes 10 cm. long, the effect of a difference of temperature of about 0.1° between the tubes should be easily observable by mere displacement, whereas a difference of less than 0.03° would be equivalent to the passage of one interference ring.

Again from equation (2), if $\Delta N = 10^{-4}$ cm. then $\Delta H = 10^{-4}/.351 = 10^{-4} \times 2.8$ cm. or about 9×10^{-5} cm. per vanishing interference ring are the displacements to be anticipated. These are equivalent to pressures of about 0.3 and 0.1 dynes per cm^2.

A number of experiments were made with this apparatus but for these there is no space here.

5. *Jamin's Interferometer.*—The ease with which the Michelson interferometer may be adjusted and its remarkable adaptability have led to its general preference over the older form of Jamin. Nevertheless the latter furnishes two parallel rays which for such purposes as the present are desirable. Hence if the four faces of the interferometer be separated in the manner suggested by Mach, a very available form of interferometer is obtained. But the trouble with the arrangement is the difficulty of adjusting the *four* surfaces. Not only are the centers of ellipses liable to be remote from the center of the field, but it is often hard, without special equipment, to even find the fringes.

If however the device which I suggested elsewhere is adopted, i.e., if figure 4, the half silvered plates, M, N, are at the ends of a simple strip of plate glass, so that rays terminating in $M\ M'\ N\ N'$ after adjustment necessarily make a rhombuslike figure symmetrical to MN the fringes are found at once: for they appear when the white slit images in T coincide horizontally and vertically and the rays bd and cd intersect in the common point d. Hence the mirrors, M', N', should be on carriages D, F, adapted to move on the parallel slides S, S'. M, N may also be put on a carriage E though this is not necessary. S, S' need not be parallel to ac or bd. If the mirror M' and N' are wide, considerable latitude of adjustment is thus obtained.

If $M\ N$ is half silvered on the same side (i.e., toward N') a compensator is needed in ac or cd, if path difference is to be annulled (symmetry). If however M is half silvered on the N' side and N on the M' side, no compensator is required. In the latter case however, if ordinary plate glass is taken, M and N are not quite parallel and the ellipses will be

eccentric. This however is not necessarily a disadvantage, unless the strip MN is excessively wedgeshaped.

The ellipses obtained are usually long vertically, so that the fringes soon become straight and the rotation is extremely rapid whenever the center of ellipses is out of the field. It is therefore possible to adjust relative to horizontal fringes (parallel to shadow of wire across slit), as these incline very obviously for a displacement of less than 10^{-4} cm. and rapidly become vertical. For this reason it makes little difference whether the half silvers are on the same or on opposite sides, or whether observation be made at T (cd prolonged) or at T' (bd prolonged). Moreover the plate MN may be conveniently constructed as in figure 5, of two mirrors m, n, attached to the clear strip of plate glass, g, by aid of strong steel clips at c, c'. With the half silvers s, s' on the same side, the wedge angle of the glass is excluded. For shorter diagonals, the plan of figure 6 with the silver surfaces s, s' held together by clips at c is preferable.

If the mirror M', figure 4, is displaced a distance e where a glass plate compensator of thickness E, and refraction constants μ and B is introduced normally either into ab or bd, the equation is easily seen to be, at wave length λ

$$E(\mu - 1) + 2B/\lambda^2 = 2e \cos\theta$$

where θ is the angle of reflection at M. Using the plate $E = 0.434$ cm. treated above, the first member is 0.2428 cm. Values of e of 0.2420, 0.2409, 0.2427 were roughly obtained. Hence the mean value of θ should be about 60°, as it actually was. Certain outstanding difficulties may be met by making MN, figure 4, the *short* diagonal of the rhombus and using the strip figure 6. In such a case θ at M' is small and in view of the nearly normal reflection at M and N relatively little reflection comes from naked glass, sliding is largely avoided and no compensator is necessary. In this case the fringes for no path difference are actually black horizontal lines on a colored ground and far enough apart that 1/10 fringe could easily be estimated. A test experiment with the above plate showed $e = 0.1244$ cm. corresponding to the small angle θ a little over 12°.

When the U-tube CC', figures 2 and 4, is introduced, the strip MN will have to be at a considerable angle (about 45°) to the horizontal, so as to raise the N end about 15 cm. above the M end, corresponding to the height of m above m' in figure 2. The new condition however in no way changes the general procedure. In case of figure 5 the mirror N'

must be high and M' low. If C' is at G' the whole of each component beam may be caught and passed through the respective shanks of the U-tube. The fringes are strong, easily found and large, so that the center of ellipses is not far outside of the field of the telescope.

Finally if the connecting tube p is nearly horizontal when in place, the fringes are usually found at about the same position of the micrometer (at M') after the liquid is introduced into the U-tube.

Experiments were also made with this apparatus. Displacement interferometers in which the rays do not retrace their respective paths have an important special property which I wish to accentuate in conclusion. If either opaque mirror is displaced on its micrometer normal to itself or if a plate compensator rotates in one beam on a vertical axis, the center of ellipses moves parallel to the length of the spectrum. If however the plate compensator rotates on a *horizontal* axis, the center of ellipses moves nearly *transversely* to the length of the spectrum. The phenomenon is quite sensitive. To this result I shall return in a succeeding note, in connection with the development of the Jamin design for displacement interferometry.

The present note will be presented in more extended form in a report to the Carnegie Institution of Washington.

ATTEMPT TO SEPARATE THE ISOTOPIC FORMS OF LEAD BY FRACTIONAL CRYSTALLIZATION

By Theodore W. Richards and Norris F. Hall

WOLCOTT GIBBS MEMORIAL LABORATORY, HARVARD UNIVERSITY

Communicated, March 10, 1917

Although the complete inseparability of isotopes by chemical means has been frequently asserted, the evidence on which this assertion is based has always seemed insufficient. The methods used have been fractional crystallization and precipitation, but these processes have seldom been carried out more than ten times in a particular case, and frequently six or seven crystallizations have been thought a sufficiently thorough test of inseparability. A search of the literature revealed only one investigation, that of Radiothorium and Thorium by McCoy and Ross,[1] where as many as one hundred repetitions of a given process had been made.

It seemed worth while, therefore, to apply to the important generalization of Fajans, Russell, Fleck and Soddy a more searching test carrying the fractionation further, and using as a criterion of success not only the measurement of radioactivity but also the determination of atomic weight.

The lead from Australian carnotite, with which the kindness of Mr. S. Radcliff and Mr. E. R. Bubb had supplied us and which had been used in previous atomic weight and density determinations in this laboratory,[2] seemed well suited to our purpose.

About 1 kilogram of this lead was converted into nitrate and used for the fractional crystallization. Lead nitrate crystallizes from aqueous solution in compact, large octahedra which can be very completely freed from mother liquor merely by drainage, and come rapidly to equilibrium with the mother liquor.

The whole of the nitrate was dissolved in distilled water and evaporated until a crust began to form. This was called fraction 1. After cooling to room temperature the mother liquor was poured off and formed fraction 2. To the crystals from fraction 1 was added sufficient water to dissolve them, and the solution was called fraction 3.

Fractions 2 and 3 were evaporated to saturation and cooled as fraction 1 had been, the liquor from 2 forming fraction 4. Fraction 5 was made by adding the liquor from 3 to the crystals from 2, and water was added to the crystals from 2 to form fraction 6. This process was continued until, as occurred first with fraction 16, one of the end fractions became too small to work with conveniently and was consequently added entire to the mother liquor from fraction 17 to form fraction 22. This expedient was resorted to wherever the end fractions became inconveniently small. In all, seventy-five courses or tiers of fractions were obtained, most of the last of which contained eighteen fractions to a tier. The number of effective crystallizations was 904.

The crystallization was carried out entirely in porcelain, at first in large evaporating dishes, then, as the fractions became smaller, in casseroles covered with watch glasses. The hot casseroles were usually set in evaporating dishes full of cold water, which was frequently changed to hasten cooling.

Centrifugal drainage was not used because, as determined by calculation, the gain in effectiveness of separation would have been less than the disadvantage caused by the increased time necessary to treat the precipitates centrifugally.

Purification.—Two samples, one from the more soluble and one from the less soluble end of the final row of crystallizations were treated in an identical manner. Chiefly to remove the large amount of silica which had dissolved from the casseroles during the fractionation, the crystals were first electrolyzed in warm concentrated solution between platinum wires. The well formed flat leaflets of lead were removed from time to time, with glass rod, rinsed with a stream from a wash bottle, and pre-

served in quartz dishes until all the metal had been deposited from the solution. The crystal were further washed from time to time, and all washings returned to the electrolysis bath, which was gradually reduced in volume as the concentration of lead became smaller. The lead crystals were then dissolved in pure nitric acid, and the excess of acid was evaporated. The crystal of lead nitrate were dissolved in the purest water, filtered through a platinum Gooch crucible, and precipitated by the addition of a large excess of redistilled nitric acid and cooling with ice. The crystal meal thus obtained was freed from adhering acid in the platinum centrifuge, washed centrifugally with purest concentrated acid and redissolved in the least possible amount of pure boiling water.

Five precipitations with centrifugal drying were made in this way. The crystals from the fifth crystallization were placed in a quartz dish and dissolved. From this solution lead chloride was precipitated by passing in pure hydrochloric acid gas made by warming the purest acid of commerce. The chloride thus obtained was dried in the centrifuge, washed with cold water, and redissolved in boiling water. Four crystallizations as chloride followed. A little hydrochloric acid was added to the solution each time to prevent the formation of basic salt and to render the chloride less soluble. The last crystals, after centrifugal washing and drying were preserved in an exhausted desiccator over fused potash. Nothing but platinum and quartz vessels were used.

The Determination of Atomic Weight.—For these determinations the usual procedure was employed. About five grams of the dried crystals were placed in a platinum boat, which with its container had been carefully weighed. The boat was gradually heated in a quartz tube attached to the usual 'bottling apparatus,' in a current of pure dry hydrochloric acid gas. After nearly all the residual water had been driven from the crystals, the temperature was raised so as to fuse the salt, which was then cooled as quickly as possible in a current of pure dry nitrogen prepared by the Wanklyn process.

After the salt had cooled, and the nitrogen had been replaced by dry air, the boat was pushed into the weighing tube, bottled, and reweighed.

The boat and salt were next heated at 80°–90° on an electric stove in a glass flask containing about a liter of water to which enough pure nitric acid had been added to prevent the formation of basic salt, until the lead chloride had all dissolved. As usual[3] a small amount of siliceous and carbonaceous residue had to be removed by scrupulously quantitative filtration through a tared Gooch-Monroe crucible. On the average, about twice as much was found in the more soluble fraction as in the

other. The weight thus removed was subtracted from the weight of the fused salt. Before filtration the boat had been carefully lifted out and thoroughly washed; and the filtration was collected in the precipitating flask.

A supposedly equivalent weight of silver was next dissolved in pure nitric acid mixed with an equal bulk of water in a flask with a chain of bulbs ground in to the neck, a steam bath being used to heat the solution. More water was then added and the temperature raised until a few seconds' gentle boiling had removed nitrous fumes. The solution having been made up to a liter, it was added very slowly with constant agitation to the lead chloride solution. Actinic light was henceforth rigorously excluded from the precipitated silver chloride. The precipitate was coagulated by violent shaking, usually for fifteen minutes, and allowed to stand at least twenty-four hours, with further occasional shakings, before samples were removed for tests. The end point was found by the customary method by means of the nephelometer, and tested for several days to be certain that it did not change.

Vacuum corrections were applied as usual, and all customary precautions were taken. The results follow.

TABLE 1

ATOMIC WEIGHTS

ORDINARY LEAD	CARNOTITE A	LEAD B
207.187	206.426	206.406
207.187	206.409	206.422
	206.431	206.399
Average.....207.187	206.422	206.409

This table includes all the analyses of these materials which were completed; any which had become the object of suspicion were rejected at an early stage.

Obviously, if the fractional crystallizations produced any change in the relative concentrations of radium G and lead, this change is very small. The means of the two series of determinations of isotopic lead differ only by about 6 parts in 100,000. This is certainly within the bounds of possible experimental error, though the low 'average errors' of the two sets (0.008 unit in each case) tempt one to assign a meaning to the observed difference. At any rate, we are safe in concluding that assuming the atomic weights of 'radium G' and lead to be 206.0 and 207.2, respectively, no change in concentration greater than 13/1200 or 1.1% has been obtained by nine hundred crystallizations. Even supposing that a real difference in solubility exists, it is evident that

complete separation could not be attained (if at all) in less than eighty thousand fractionations.

Estimation of Radioactivity.—The β-ray activity of the lead used indicates that it contains in about 2 parts so-called 'radium G' and 1 part lead, an amount of 'radium D' of the order of 10^{-7} parts. This is betrayed by the steady growth of a penetrating β-ray product (RaE) which comes to practical equilibrium with its parent in about a month after they are separated. Evidently the ionization—if the α-rays from the polonium present are cut off—caused by a weighed amount of the material under constant conditions, is a measure of the concentration of radium D relative to its isotopes 'radium G' and lead. Thus the determination of the activity of the end fractions gives information as to the relation between the solubility of the nitrate of 'radium D' and the mean solubility of the nitrates of 'radium G' and ordinary lead, a relation of great interest because it cannot be tested by atomic weight determinations. This case should afford an especially favorable test of the theory of complete identity.

The method was as follows: To eliminate differences in moisture content, and consequently in absorbtive power, the two samples were kept in the same exhausted desiccator after purification. When sixty-six days had elapsed 10.25 ± 0.03 gram of each sample was weighed into a marked metal dish and tamped with a platinum spatula. The material formed a layer of thickness defined by the expression 0.88 g/cm.^{2} This is far too thin to give a maximum ionization due to the complete absorption of the β-rays from the lowest layers, but is thick enough so that no great accidental changes in thickness needed to be feared, and the effect of small changes was annulled as described below. The dishes were covered in turn with the same thin sheet of paper and introduced into a grounded aluminum-leaf electroscope which was very kindly loaned by Prof. William Duane. The rate of fall of the leaf was then observed with a stop-watch in the usual manner. All errors arising from differences of potential, differences of stiffness of the leaf in different positions, and inhomogeneity of the scale were eliminated in the usual way. The two dishes were introduced alternately into the electroscope to eliminate the effect of changes in the natural leak, and were thoroughly stirred and repacked between every two measurements to allow for small accidental differences in thickness, and other precautions to cut out extraneous effects and secure exact comparability were employed.

It is believed that the table below, which includes all the observations affected by no known source of error, represents about as good reproducibility as this electroscope can be made to give.

TABLE 2

β-RAY ACTIVITIES

SAMPLE A

11.30; 11.43; 11.69; 11.56; 11.61; 11.47; 11.49; 11.50; 11.41; 11.58 Mean 11.504.

SAMPLE B

11.32; 11.62; 12.06; 11.43; 11.70; 11.34; 11.32; 11.43; 11.47; 11.36; Mean 11.505.

The ionization is expressed in arbitrary units (scale divisions per minute.) The natural leak (which must have been the same for both as they were taken alternately) was found to be 0.50 ± 0.01. The agreement of the averages to one part in ten thousand must be regarded as fortuitous, since their mean probable error is about 0.11 unit. This error, divided by the mean value from which has been subtracted the natural leak may be taken, roughly, as a measure of the accuracy of the determination. Its value is $\frac{11}{1150-50} = \frac{1}{100}$. This work definitely shows, then, that no change in the relative concentration of radium D and its isotopes as great as one per cent has occurred in nine hundred fractionations, and certainly gives no indication that *radium D* could be completely separated from its isotopes by this method even by crystallizing as many as 90,000 times.

If ordinary lead is a mixture of isotopes, this mixture must have been made very long ago while the earth was still in a highly mobile condition (since all the ordinary lead throughout the world seems to have the same atomic weight[4]). Could the composite nature of ordinary lead be proved, the identity of the several samples through geological aeons would form another argument in favor of the inseparability of the constituents.

To the Carnegie Institution of Washington we are greatly indebted for some of the apparatus and material used in this research, which is to be continued in the near future.

Summary.—Lead from Australian carnotite (believed to contain about one part of ordinary lead to two parts of radium G, with a mere trace of radium D) has been fractionally crystallized over nine hundred times as nitrate, and the end-fractions purified.

The atomic weights of the samples so obtained from the crystal and the mother liquor ends of the series respectively agreed within the experimental error of 6 parts in 100,000.

The β-ray activities agreed within the experimental error of 1%.

These observations indicate that the nitrates of Radium D and lead on the one hand and radium G and lead on the other hand could hardly be separated, if at all, by less than 80,000 or 100,000 crystallizations.

Hence one might infer that the molal solubilities of the nitrates are probably essentially identical. The outcome gives strong experimental support for the hypothesis that isotopes are really inseparable by any such process as crystallization.

[1] *J. Amer. Chem. Soc., Easton, Pa.*, **29**, 1907, (1709).
[2] Richards and Wadsworth, These PROCEEDINGS, **2**, 1916, (505, 694).
[3] Richards and Wadsworth, *J. Amer. Chem. Soc. Easton, Pa.*, **38**, 1916, (2616).
[4] Baxter and Grover, *Ibid.*, **37**, 1915, (1058).

HYBRIDS OF ZEA TUNICATA AND ZEA RAMOSA

By G. N. Collins

BUREAU OF PLANT INDUSTRY, U. S. DEPARTMENT OF AGRICULTURE

Communicated by E. F. Smith, March, 16, 1917

Zea tunicata and *Zea ramosa* are the two most striking variations or mutations from normal maize. Though usually referred to as agricultural species they seem to deserve a place with the so-called species of Oenothera which have originated by mutation.

The chief characteristic of *Zea tunicata* is that the glumes of the female inflorescence, or ear, are developed so that each seed is entirely enclosed. Associated with this character is a less conspicuous lengthening of the glumes of the staminate inflorescence that results in a thickening of the tassel.

The origin of *Zea tunicata* is not known, but its occurrence in widely separated and isolated regions would indicate that it has originated independently more than once, presumably as a mutation from ordinary maize.

In hybrids with non-tunicate varieties the tunicate character behaves as a dominant, but in our experiments it has never been possible to secure a homozygous tunicate strain. Progenies resulting from the selfing of tunicate plants have always shown segregation into approximately three tunicate plants to one normal.

The tunicate plants in self-pollinated progenies are separable into two classes, one producing typical tunicate ears and thickened tassels like the parent plant, and the other with greatly enlarged tassels containing both staminate and pistillate flowers, and with the ear either aborted or bearing greatly enlarged and usually sterile spikelets. This last class represents approximately one-third of the tunicate plants. Although these plants produce what appears to be normal pollen in the terminal inflorescence the long glumes never open and the pollen is not shed, and we have not been successful in securing selfed seed of this form.

The ratios in which the different classes occur indicate that the class with the bisexual terminal inflorescence is the homozygous form, and that the ordinary tunicate plants represent the heterozygous form, a cross between the form with the bisexual inflorescence and the normal non-tunicate maize.

From experiments involving forty-three progenies derived from three distinct sources, it would appear that the ordinary type of tunicate ear represents an example of imperfect dominance as unfixable as the Andalusian fowls, but since other workers report the existence of pure tunicate strains it may be that other stocks behave differently.

The class with bisexual terminal inflorescence, which is here considered homozygous, will be referred to as full-tunicate and the ordinary tunicate type, which is looked upon as heterozygous, will be termed half-tunicate. The term tunicate or podded will be used as a general term including both of the above classes.

Zea ramosa or branched maize, discovered by Dr. W. B. Gernert[1] at the Illinois Agricultural Experiment Station, differs from normal maize in having the pistillate inflorescence or ear which is normally simple replaced by a compound inflorescence. There is also a less striking but equally significant change in the branching of the terminal inflorescence or tassel. In normal maize the terminal inflorescence bears a number of branches at its base. Above the uppermost branch the axis is continued into what is termed the central spike where the pairs of spikelets are borne directly on the axis of the inflorescence. There is thus in passing from the base to the tip of the tassel an abrupt transition from the uppermost branch to simple pairs of spikelets. In the *Zea ramosa* tassel the branches are much more numerous and gradually decrease in size from the base upward, the transition from branches to pairs of spikelets being imperceptibly gradual.

Unlike *Zea tunicata*, *Zea ramosa* is a recessive variation. The dominance of normal maize over this variation seems complete. It has not been possible in any way to distinguish between plants heterozygous for the ramosa character and normal maize. So far as observed, the character behaves as a simple Mendelian unit.

Both *Zea ramosa* and *Zea tunicata* are variations from normal maize toward the general type of grasses, and as such may be looked upon as reversions, since both cases involve a loss of a specialization that distinguishes maize from practically all other grasses.

Description of the Hybrid.—The cross between *Zea tunicata* and *Zea ramosa* was made in 1914. Nine first-generation plants of this cross were grown in 1915. Of these four were tunicate, and five normal,

indicating the heterozygous nature of the half-tunicate parent plant. The tunicate plants were all half-tunicate, and no trace of the ramosa characters could be seen.

Five self-pollinated first-generation ears were selected for planting in 1916. Three of these ears were tunicate and two normal. Four hundred and eight second-generation plants were matured in 1916—326 from the three tunicate ears, and 82 from the two non-tunicate ears of the first generation.

The progeny of the non-tunicate or normal F_1 plants showed segregation into normal and ramosa in the ratio of 3 to 1, the numbers being 65 normal and 17 ramosa. In none of these plants was there evidence of tunicate characters.

It was possible to classify the F_2 plants descended from the tunicate F_1 ears into (1) Normal, (2) Half-tunicate, (3) Full-tunicate, (4) Ramosa, and (5) Tunicate-ramosa. The last class comprised those plants in which both tunicate and ramosa characters could be recognized. When both the staminate and pistillate inflorescences were considered the classes were well marked.

In the tunicate-ramosa group there were many plants with an entirely new type of inflorescence. In these the branching habit, which suggests that of the ramosa parent, was developed to a grotesque extreme. As soon as branches formed these again branched. This division continued until the end of the growing season when the tissue was still in an embryonic condition and nothing resembling floral or foliar organs was formed. The result was a white succulent mass. This peculiar formation occurred in both lateral and terminal inflorescences, though it was much more common in the former, and in terminal inflorescences it was usually confined to the basal branches.

This type of inflorescence is similar, if not identical, with an abnormality discovered by Blaringhem in a strain of *Zea tunicata*[2] and termed by him 'cauliflower.'

It was found possible to account for the ratios by the assumption of relatively simple gametic composition. The tunicate character is represented by T and its recessive allelomorph, the normal condition, by T′. The recessive ramosa character is represented by R′ and its dominant allelomorph, the normal condition by R.

The observed numbers compared with the numbers expected in accordance with this gametic composition are given in the following table.

NUMBER EXPECTED OUT OF EACH 16	GAMETIC COMPOSITION	CHARACTERS OF PLANT	EXPECTED NUMBERS	OBSERVED NUMBER
1	T′ T′ R R	Normal	61.2	64
2	T′ T′ R R′	Normal		
2	T T′ R R	Half-tunicate	122.0	121
4	T T′ R R′	Half-tunicate		
1	T T R R	Full-tunicate	61.2	61
2	T T′ R R′	Full-tunicate		
1	T T R′ R′	Tunicate ramosa	61.2	64
2	T T′ R′ R′	Tunicate ramosa		
1	T′ T′ R′ R′	Ramosa	20.4	16
Total.....			326.0	326.0

In each of the parent varieties there is a deviation from normal maize in both the staminate and pistillate inflorescences. It is of interest, therefore, to determine so far as possible whether the changes in the two parts of the plant are due to a single gametic change, or whether they may be inherited separately.

With this point in mind the plants were classified with respect to their tassels, and ears, independently, with the following results:

The normal plants were all normal in both tassel and ear.

The distinction between half- and full-tunicate is somewhat arbitrary, but with one exception all the 121 plants classified as half-tunicate by their tassels also had ears classed as half-tunicate. That the distinction is genetic and not merely physiological is indicated by the absence of any sensible correlation between the length of the staminate and pistillate glumes on the individuals inside the half-tunicate group.

Of the 53 plants classed as full-tunicate by their tassels, all but two had either full-tunicate ears, or none at all, and the two exceptions had pistillate glumes only slightly below 45 mm., the minimum length set for the glumes of full-tunicate ears. There is then almost a perfect correlation between the type of tassel and ear, but here again there is no correlation inside the group. That is, long glumes in the tassel were not correlated with long glumes on the ear. Even the extreme form of full-tunicate plants that produced no ears did not differ, with respect to the length of the staminate glumes, from the plants bearing ears.

When both tunicate and ramosa characters were present in the ears, the tassels were always ramosa but the tunicate characters were not always apparent in the tassel.

Conversely, the 53 plants with ramosa tassels all exhibited ramosa characters in the ears, either pure or combined with the tunicate character.

Perhaps the most interesting class of plants were those with cauli-

flower inflorescences. This peculiar type of pistillate inflorescence seems definitely confined to the class of plants combining the tunicate and ramosa characters.

The cauliflower character, which in itself would seem more nearly related to ramosa than to tunicate, is somewhat more definitely associated with the ramosa than with the tunicate character of the tassels.

There were 22 plants with pure cauliflower ears. Twenty of these had tassels in which both tunicate and ramosa characters were obvious. The other two were classed as having ramosa tassels. Of the 13 plants with partial cauliflower ears 11 had ramosa tassels in which no tunicate characters were observed, and two showed evidence of both tunicate and ramosa in their tassels.

If the second-generation plants are examined for each of the parental types separately, there is seen to have been a simple 1 to 3 segregation in both instances. One-fourth of the total number of plants are ramosa and three-fourths non-ramosa (observed 79 to 247, expected 81.5 to 244.5). One-fourth are non-tunicate and three-fourths tunicate (observed 80 to 246, expected 81.5 to 244.5). The distinction between half- and full-tunicate could not be made when these characters were combined with the ramosa character. The various combinations of parental characters, occurring as they do in the normal di-hybrid ratios, show that the tunicate and ramosa characters are not genetically correlated.

The extended publication will appear in the *Journal of Agricultural Research.*

[1] Gernert, W. B., A new subspecies of zea mays L., *Amer. Nat., Lancaster, Pa.*, 1912, 46 (616-622).

[2] Blaringhem, Louis, *Mutation et traumatismes*, Paris, 1907, (121–122).

DISTRIBUTION OF GALL MIDGES

By E. P. Felt

NEW YORK STATE MUSEUM, ALBANY, NEW YORK

Communicated by J. M. Clarke, March 12, 1917

The intimate relation existing between many species of these tiny, fragile flies and their food plants and the relatively limited migratory ability of either adults (owing to their weak powers of flight), or the larvae (due to their apodous or nearly apodous condition), led to a study of the distribution of these highly variable forms. The immensity of the complex may be appreciated by remembering that approximately three hundred genera and probably nearly three thousand species are known—the largest about 6 mm. in length and the smallest less than 0.5 mm. long. Some live in decaying or dead organic matter, others

prey upon mites and certain insects, while a very large majority produce characteristic galls upon the different parts of a great variety of plants. Not a few are inhabitants of blossom buds, with a very limited period for feeding and growth and an extended estivation or hibernation, while many others pursue these vital activities through most of the growing season. Summarizing, we may state that great structural variations and equally marked physiological and ecological adaptations are accompanied by a puny organization and a world-wide distribution. What are the most important factors which have brought this about?

It is impossible, owing to the limited knowledge of this group from important faunal regions, to present a complete story. Fortunately there are a number of genera with sufficiently well marked characters as to render their identification reasonably certain, and for a number of these there are records from such widely separated localities as to justify the characterization of their distribution as world-wide. The presumption is against their occurring in all faunal regions, though they probably exist in most places where climate and flora combine to make this possible. There are in addition to the above, a number of genera which have been recorded from such distant countries as to justify the suspicion that they likewise may have a world-wide or nearly world-wide distribution. A tabulation of these genera is given below.

ITONID GENERA OF PRESUMABLY WORLD-WIDE DISTRIBUTION

TRIBE AND GENUS	NORTH AMERICA	SOUTH AMERICA	EUROPE	ASIA	AFRICA	AUSTRALIA	NEW ZEALAND
Lestremiinariae							
Catocha Hald.	+		+				
*Lestremia Macq.	+	+	+	+		+	+
Campylomyzariae							
*Campylomyza Meign.	+		+			+	+
*Joannisia Kieff.	+		+		+†		
Heteropezinae							
Oligarces Mein.	+		+				
*Miastor Mein.	+		+			+	+
Leptosyna Kieff.	+		+				
Brachyneura Rond.	+		+				
Spaniocera Winn.			+			+	
Porricondyliariae							
Didactylomyia Felt.	+			+			
Holoneurus Kieff.	+		+				
*Colpodia Winn.	+		+	+		+	
Dirhiza H. Lw.	+		+				
Porricondyla Rond.	+		+		+	+	+
Camptomyia Kieff.	+		+				
Rubsaamenia Kieff.	+	+	+				
*Asynapta H. Lw.	+		+	+		+	
Winnertzia Rond.	+		+			+	

ITONID GENERA OF PRESUMABLY WORLD-WIDE DISTRIBUTION—*Continued*

TRIBE AND GENUS	NORTH AMERICA	SOUTH AMERICA	EUROPE	ASIA	AFRICA	AUSTRALIA	NEW ZEALAND
Dasyneuriariae							
Cystiphora Kieff.	+		+				
Rhabdophaga Westw.	+		+				
Dasyneura Rond.	+	+	+	+	+	+	
Diarthronomyia Felt.	+		+				
Lasiopteryx Westw.	+		+				
Oligotrophiariae							
Rhopalomyia Rubs.	+	+	+	+	+		
Oligotrophus Latr.	+	+	+	+	+	+	
Janetiella Kieff.	+	+	+				
Phytophaga Rond.	+		+			+	
Asphondyliariae							
Schizomyia Kieff.	+		+	+	+		
§Cincticornia Felt.	+		+			+	
Asphondylia H. Lw.	+	+	+	+	+	+	
Lasiopterariae							
Trotteria Kieff.	+		+				
*Lasioptera Meign.	+	+	+	+	+	+	
Aplonyx De Stef.	+		+				
Clinorhyncha H. Lw.	+		+				
Itonididinariae							
Contarinia Rond.	+		+			+	
Thecodiplosis Kieff.	+		+				
Dentifibula Felt.	+			+			
Dicrodiplosis Kieff.	+		+				
Bremia Rond	+		+				
Aphidoletes Kieff.	+		+			+	
Karschomyia Felt.	+	+					
Mycodiplosis Rubs.	+	+‡	+	+			
Clinodiplosis Kieff.	+	+	+	+			
Diadiplosis Felt.		+		+			
Arthrocnodax Rubs.	+	+	+	+			
Hormomyia H. Lw.	+		+				
Pseudhormomyia Kieff.	+		+	+			
Monarthropalpus Lab.	+		+				
Hyperdiplosis Felt.	+	+‡					
Lestodiplosis Kieff.	+	+	+	+	+	+	
Itonida Meign.	+	+	+	+		+	+
Parallelodiplosis Rubs.	+		+				
Cystodiplosis Kieff and Jorg.	+	+					

* Recorded from the Baltic amber of the upper Eocene.

† Seychelles.

‡ St. Vincent.

§ Polystepha Kieff. and Eocincticornia Felt are included because of obvious affinities.

An examination of the above tabulation shows that representatives of all the tribes are known from most of the continental areas and probably occur on all, since allowance should be made for our scanty

knowledge of the fauna in the more remote regions. Furthermore, the more primitive genera, such as Lestremia, Campylomyza, Porricondyla, Dasyneura, Oligotrophus, Asphondylia, Lasioptera, Contarinia and Lestodiplosis, to take representatives from the various tribes, are found on most of the continental areas. They are represented among living forms by numerous species, many of them capable of subsisting under comparatively simple conditions and therefore not easily exterminated or isolated by adverse climatic changes.

It is noteworthy that of the seven genera known from the Baltic Amber, six are recorded also from Australia, three from New Zealand and two from Africa, and in all probability more of these genera occur in the land areas of the Southern Hemisphere. The African, Australian, New Zealand and South American faunae appear to contain a considerable number of ancient, highly specialized offshoots from the somewhat primitive world-wide genera (likewise represented) mentioned above and their occurrence suggests a zoological isolation where only the more vigorous or adaptable would establish themselves and where the natural tendency to variation would consequently be less subject to interference on the part of closely related strains or species in the process of formation.

One of the striking peculiarities in distribution is the occurrence of the genus Aplonyx in the Northern Hemisphere, where it is known only from the Mediterranean region and the vicinity of Salt Lake, Utah—localities favored by both host plants and insects. Species of Didactylomyia, a very peculiar form, occur in both North America and India, while the closely related Erosomyia and Indodiplosis are occidental and oriental, respectively.

The above and other data which need not be discussed in detail here, suggest no connection between food habits and a general distribution, since there does not appear to be a better representation of midges, such as Lestremia and Porricondyla breeding in decaying vegetable or woody tissues, materials which might easily drift to distant shores, than there is of bud or leaf-inhabiting forms which find only temporary shelter in plants and transform in the soil, such as species of Dasyneura and Contarinia. The same is true of species passing most of their existence within plant tissues, such as Lasioptera and Rhabdophaga, forms most likely to be carried great distances with the host plant. An equally wide distribution is true of predaceous midges with only a secondary relation to plants, such as Aphidoletes, Mycodiplosis and Arthrocnodax.

It is possible that some species may be widely disseminated through

the agency of birds, since we have records of birds feeding upon the galls of Cincticornia and there would appear to be no reason why those produced by the genus Caryomyia might not be equally acceptable. The same would be true to a certain extent of galls inhabited by Asteromyia and some species of Oligotrophus. It would be possible for midge larvae in firm, moderately thick-walled galls, to pass through the digestive tract of the bird without material injury, but this would be true of relatively few and owing to obvious limitations we can hardly consider this method of dissemination as one of great importance so far as the group as a whole is concerned.

The flight of gall midges, especially such a one as Miastor, is so feeble as to render it improbable that the wings of themselves are important in distributing the species over extended areas, and yet these midges are surprisingly prevalent where breeding conditions are favorable. The adults issue in swarms from decaying logs and apparently drift with the wind. The probability of this method of spread being an important one is supported by the recent investigations of McCulloch,[1] which show that Hessian flies may drift at least 2 miles with the wind. It is probable that this method of dissemination is very effective in the case of a number of gall midges.

Extended drifting, some possibly may prefer the word flight, with the wind, is not impossible when we recall that the migratory locust, Schistocerca peregrina has been found five hundred miles east of South America and is credited with probably having crossed from South America to Africa. Such extended flights are rendered more likely by the record of Sphinx convolvulus being found 420 miles from land, while other moths and longicorn beetles have been reported out at sea at a distance of 230 miles. The extensive northern flight of the cotton moth is another case of the same kind. Recent investigations by Collins[2] have shown that young gipsy moth caterpillars may be carried 20 to 25 miles by the wind—a distance which presumably could be greatly increased without endangering larval existence.

With the above data in mind it seems probable that the carriage of gall midges by floating vegetation and drifting islands, or by the activities of birds, has occurred to only a very limited extent and can not begin to explain the general distribution of these fragile forms. Winds undoubtedly carry these insects for short distances and might even, under exceptional conditions, transport them over seas, though this latter is by no means established and the present known distribution appears to be most easily explained by migrations (probably drifting with the wind in this group) over land areas about the same way as other mem-

bers of the fauna and the flora. There has been very probably a distribution from the north and there may have been an antarctic center of dispersion, though there appears to be no evidence within the group itself which would justify a definite opinion as to this.

[1] McCulloch, *Econ. Ent. J.*, 10, 1917, (162–168).
[2] *Ibid.*, 10, 1917, (170–176).

FERTILITY AND AGE IN THE DOMESTIC FOWL

By Raymond Pearl

BIOLOGICAL LABORATORY, MAINE AGRICULTURAL EXPERIMENT STATION

Communicated March 22, 1917

It has been shown by Marshall,[1] Pearl,[2] and King,[3] that in a variety of different mammals fertility changes with the age of the animal in a definite way. The nature of this change is that, starting at a low point at the beginning of the sexual life, the rate of fertility rises with advancing age to a maximum, and then declines with further increase in age, until total sterility is reached. Marshall inclined to the view, on the basis of statistics which I have elsewhere[4] shown to be wholly inadequate, that the domestic fowl exhibited the same sort of change in fertility with age. There has been no thorough or careful investigation of this matter in the fowl, based on adequate statistical material.

The writer has lately studied[5] the change in fertility with age in poultry, on the basis of 1114 matings of Barred Plymouth Rock fowls, covering in point of time a period of nine years. For the purposes of this investigation, and generally, the writer has defined *fertility* as the total net reproductive capacity of pairs of organisms, male and female, as indicated by their ability to produce *viable* individual offspring. As a working measure of fertility may be taken a reproductive or fertility index which expresses the percentage which the number of viable offspring actually produced from a particular mating or pair of parents is of the maximum number which would be physiologically possible within the time limits during which the mating endures. This states, in most general terms, the form of index developed for the special case of poultry breeding in the present investigation. The same idea can be adapted to the measurement and biometrical study of fertility in other sorts of animals, and probably in plants as well.

Specifically, the reproductive, or fertility index used in the work for poultry has the following form:

$$RI = 100C/E_m$$

where RI denotes the index for any particular mating, C the number of chickens produced from that mating and alive at the end of the third week after hatching, and E_m the total number of days from the day when this mating began to the day when the last egg from this mating began its incubation.

The reasoning on which this index is based is as follows: Maximum reproductive capacity, as represented by 100%, would be attained if during the period of the mating the hen laid one egg every day (maximum fecundity), and if further every one of such eggs were fertile, and if each embryo hatched, and the hatched chick lived to be three weeks of age. There would then be one living chick three weeks of age for each day during which the mating existed. If the hen does *not* lay every day during the mating season this will cause some reduction in the reproductive performance as measured by the index. Similarly a reduction in any of the other factors involved, prenatal or postnatal mortality, will have the same sort of result. The final percentage value which one obtains by calculating the index will be a true measure of the reproductive capacity of that mating, including within its view all of the primary factors of reproduction in poultry.

Applying this index to the problem of changing fertility with advancing age we have the following results:

Weighted mean reproductive indices for males of specified ages mated with females of all ages

Ages	*Weighted mean RI*
Male = 1, mated with ♀ ♀ of all ages	12.868
Male = 2, mated with ♀ ♀ of all ages	10.214
Male = 3, mated with ♀ ♀ of all ages	9.625

Weighted mean reproductive indices for females of specified ages mated with males of all ages

Ages	*Weighted mean RI*
Female = 1, mated with ♂ ♂ of all ages	12.765
Female = 2, mated with ♂ ♂ of all ages	11.660
Female = 3, mated with ♂ ♂ of all ages	10.722

From these figures it appears that there is a decline in net reproductive ability or fertility, as measured by the reproductive index, with advancing age in both sexes. The rate of the decline is, however, more rapid in the male than in the female.

It is desirable also to look at the matter from the standpoint of the mating. This may be done by taking means (weighted in proportion to the frequencies involved) of the reproductive indices for the advancing combined ages of the two animals entering into each class of matings. If this is done we get the following results:

Weighted mean reproductive indices for matings of individuals of the specified combined ages

Combined ages of mated individuals when mated	*Cases*	*Weighted mean RI*
2 years	796	13.083
3 years	190	11.121
4 years	113	11.119
5 years	12	7.458

The cases are too few to give reliable results after a combined age of four years. Up to that point, however, what occurs is this: There is a significant drop in reproductive ability as we pass from a combined age of two years for the mated birds to three years. In passing from three years to four there is no significant change in reproductive ability. In passing from a combined age of four years to that of five years there is a large drop in the net reproductive ability of the mating.

All of these figures agree in indicating that in the strain of the domestic fowl with which this work was done there is nothing approaching that law of fertility which has been found to hold for mammals, as pointed out at the beginning. Instead we find a steady and progressive decline in fertility after the first breeding season.

[1] Marshall, F. N. A., *The Physiology of Reproduction*, London, 1910, xvii + 706 pp.
[2] Pearl, R., *Science, New York*, N. S., 37, 1913 (226–228).
[3] King, H. D., *Anat. Rec., Philadelphia*, 11, 1916 (269–289).
[4] Pearl, R., *J. Exp. Zool., Philadelphia*, 13, 1912 (155–268).
[5] A complete and detailed report of this work will appear presently in *Genetics*.

A KINETIC HYPOTHESIS TO EXPLAIN THE FUNCTION OF ELECTRONS IN THE CHEMICAL COMBINATION OF ATOMS

By William A. Noyes

DEPARTMENT OF CHEMISTRY, UNIVERSITY OF ILLINOIS

Read before the Academy, April 16, 1917

Beginning with Davy[1] and Berzelius, during the first part of the nineteenth century chemists generally accepted the theory that chemical combination is due to electrical forces, but when Dumas discovered the chloroacetic acids in which chlorine atoms, supposedly negative, replace positive hydrogen atoms it was believed that the theory had been shown to be false and it was practically abandoned. Following this, for fifty years or more, a theory of valence which took no account of electrical forces was developed and while occasional reference was made to positive and negative atoms and groups, no definite meaning in an electrical sense was attached to these expressions. Helmholtz in his Faraday lecture in 1881[2] drew the attention of chemists once more to the very

close connection between chemical forces and electrical phenomena and spoke for the first time of "atoms of electricity." He also pointed out that the "sulphur of sulphuric acid must be charged with positive equivalents of electricity." In 1887 Arrhenius proposed his theory of electrolytic dissociation and with the help of Ostwald and van't Hoff the belief in a separation of molecules into electrically charged parts in solutions was rapidly accepted. J. J. Thompson[3] gave precision to the atomic character of electricity in 1897 when he demonstrated the material character of cathode rays and the very minute mass of the corpuscles carrying negative charges. Van't Hoff[4] seems to have suggested for the first time that electrically charged atoms may play a part in reactions not usually considered as ionic. The same idea was proposed by the author[5] and by Stieglitz,[6] a little later. J. J. Thompson[7] seems to have been the first to suggest that two atoms may be held together by the electrical foreces resulting from the transfer of an electron from one to the other. He assumed a shell of electrically positive matter within which there was a static arrangement of electrons. Abegg[8] in an entirely independent paper published the same year, discussed the relation between electrons and ionization and the connection with older theories of Helmholtz and others. He also raises, I think for the first time, the question of polar and non-polar volences but seems to have decided that the former are more probable.[9] Rutherford[10] has advanced strong reasons for considering that atoms contain a positive nucleus around which electrons are rotating and this hypotheses has been further developed by Bohr,[11] Nicholson,[12] Moseley[13] and others,

Physicists in general have directed their attention to rotating or rapidly moving electrons and to the relation between these and spectral lines, the disintegration of atoms and other phenomena involving individual atoms. Chemists, on the other hand, following the suggestion of J. J. Thomspson, have considered chiefly the rôle which the valence electrons probably play in the combination of atoms. Sir William Ramsay[14] in his address on "The Electron as an Element" considered that the electron takes a position between the two atoms which are held in combination. In a very recent paper, probably the last which he wrote,[15] he elaborates this thought further and describes models to illustrate the magnetic attractions which would result from electrons rotating in contiguous parts of two molecules. The magneton theory of the structure of the atom has also been developed elaborately by Parson.[16] It cannot account for ionization, where, if we accept the electron theory at all, electrons must be transferred completely from the positive atom or group to the negative.

Falk and Nelson,[17] Fry,[18] L. W. Jones,[19] Stieglitz[20] Bray and Branch,[21] G. N. Lewis,[22] and others have discussed the phenomena connected with the transfer of valence electrons from one atom to another but, with the exception of the magneton theories referred to above, no one, so far as I can discover, has suggested a possible connection between the motion of the valence electrons and chemical combination between atoms.

In the hypotheses here proposed the following assumptions, now more or less current among physicists and chemists, are made:

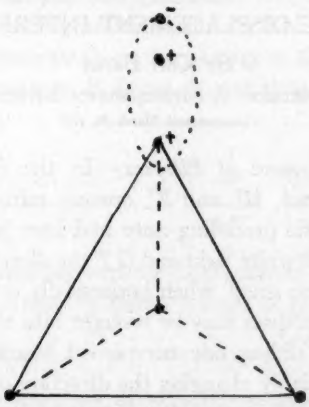
1. The atoms are of a complex structure made up of positive nuclei and electrons, of which the latter, at least, are in very rapid motion. If we assume that the electrons are 1/1800 the mass of hydrogen atoms and that they obey the same laws of motion as other atoms, their average velocity would be about sixty times the velocity of molecules of hydrogen (H_2). I will not attempt to discuss here the question whether the law of equipartition of energy actually holds for electrons.

2. That the electrons are of two kinds in their relation to the structure of the atom. Some of them are so involved in their orbits or motions among the positive nuclei that they can never escape from the atom. Others, called valence electrons, may be transferred to other atoms.

Let us suppose that two atoms, which have an affinity for each other are brought close together. A valence electron which is rotating around a positive nucleus in the first atom may find a positive nucleus in the second atom sufficiently close so that it will include the latter in its orbit and it may then continue to describe an orbit about the positive nuclei of the two atoms. During that portion of the orbit within the second atom that atom would become, on the whole, negative while the first atom would be positive. During the other part of the orbit each atom would be electrically neutral, and the atoms might fall apart. When we remember, however, the tremendous velocity of the electrons and the relatively sluggish motions of the atoms it seems evident that the motion of an electron in such an orbit might hold two atoms together. In ionization the electron would, of course, revolve about the nucleus of the negative atom leaving the other atom positive. It seems impossible to explain ionization otherwise than on the supposition of the complete transfer of the electron. This complete transfer in ionization is one of the strongest arguments against the magneton theory as the only explanation of chemical combination.

An interesting feature of the hypothesis proposed is that it may be used to account for that localization of the affinities in particular parts

of atoms which is indicated by many of the properties of organic compounds. Thus if we suppose that there are four (or eight) positive nuclei in a carbon atom around which valence electrons may rotate, an atom of hydrogen may be held to the neighborhood of one of these nuclei as indicated in the figure.



I wish to acknowledge my indebtedness to Julius Stieglitz, R. D. Carmichael, J. B. Shaw, Jacob Kunz, A. P. Carman, A. A. Noyes and R. C. Tolman, who have read the first draft of this paper and of whom several have made helpful suggestions.

[1] Davy, *London, Phil. Trans. R. Soc.*, 1807, p. 1.
[2] Helmholtz, *London, J. Chem. Soc.*, **24**, 1881, (291).
[3] Thomson, J. J., *Phil. Mag., London*, (Ser. 5), **44**, 1897, (291).
[4] Van't Hoff, *Ibid.*, **23**, 1901, (797).
[5] Noyes, W. A., *J. Amer. Chem. Soc., Easton, Pa.*, **23**, 1901, (463).
[6] Stieglitz, *Ibid.*, **23**, 1901, (797).
[7] Thomson, J. J., *Phil. Mag., London*, (Ser. 6), **7**, 1904, (237).
[8] Abegg, *Zs. Anorg. Chem., Hamburg*, **39**, 1904, (330).
[9] *Loc. cit.*, Note 8, p. 347.
[10] Rutherford, E., *Phil. Mag., London*, (Ser. 6), **21**, 1911, (669).
[11] Bohr, N., *Ibid.*, **26**, 1913, (1, 476, 857). On p. 862 Bohr discusses the hypothesis that atoms may be held in combination by electrons rotating about the line joining the positive nuclei of two atoms. This is similar to Ramsay's view mentioned below.
[12] Nicholson, *Phil. Mag., London*, (Ser. 6), **27**, 1914, (54).
[13] Moseley, *Ibid.*, **26**, 1913, (1024).
[14] Ramsay, Sir W., *London, J. Chem. Soc.*, **93**, 1908, (774).
[15] Ramsay, Sir W., *London, Proc. R. Soc.*, (A), **92**, 1916, (451.)
[16] Parson, A magneton theory of the structure of the atom, *Washington, Smithsonian Inst., Misc. Collect.*, **65**, 1915, No. 11.
[17] Falk and Nelson, *New York, Sch. Mines Q., Columbia Univ.*, **30**, 1909, (179)., *J. Amer. Soc., Easton, Pa.*, **32**, 1910, (1637).

[18] Fry, *J. Amer. Chem., Soc., Easton, Pa.*, **34**, 1912, (1268), *Zs. physik. Chem., Leipzig*, **76**, 1911, (385, 398, 591).

[19] Jones, L. W., *J. Amer. Chem., Easton, Pa.*, **36**, 1914, (1268).

[20] Stieglitz, *Ibid.*, **36**, 1914, (272); **38**, 1916, (2046).

[21] Bray and Branch, *Ibid.*, **35**, 1915, 1913, (1440).

[22] Lewis, G. N., *Ibid.*, **35**, 1915, (1448).

TRANSVERSE DISPLACEMENT INTERFEROMETRY

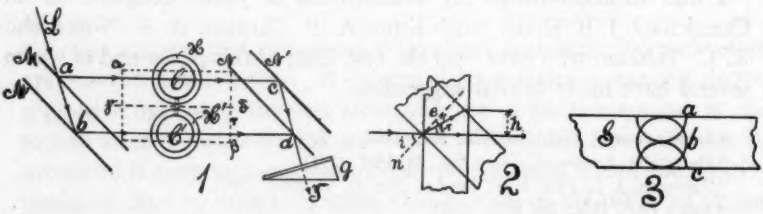
By Carl Barus

DEPARTMENT OF PHYSICS, BROWN UNIVERSITY

Communicated March 26, 1917

1. Vertical Displacement of Ellipses.—In the diagram figure 1, M and N are half silvered, M' and N' opaque mirrors; C and C' the U tube referred to in the preceding note and here to be removed. L is the collimated beam of white light and $G\,T$ the direct vision spectroscope.

If the fringes are too small, when horizontally centered by the micrometer, the center of ellipses may be brought into the middle of the field of the telescope by sliding one component beam vertically over the other without appreciably changing the direction of the rays. In other words one illuminated spot at d, figure 1, is to move vertically relative



to the other by a small amount. This may be done by placing a thick plate glass compensator such as is seen in figure 2 in each of the component beams *abd* and *acd* and suitably rotating one plate relative to the other, each on a horizontal axis. Very little rotation is required. In the same way elliptical fringes may be changed to nearly linear horizontal fringes when desirable. If the fringes are to be sharp the slit must be very fine. When sunlight is used with a slit not too fine, each of the coincident sodium lines (D_1D_2) frequently shows a sharply defined helical or ropelike structure. This is a special phenomenon, which will be given further consideration presently.

The first result is interesting inasmuch as it is thus possible to displace the centers of ellipses not only horizontally as usual relative to the fixed sodium lines in the spectrum, but also *vertically* relatively to

the fixed horizontal shadow in the spectrum due to the fine wire across the slit. It does not occur when rays retrace their path. The following experiment was made to coordinate the vertical displacement of the component rays and centers of elliptic fringes. A glass plate $d=0.705$ cm. thick was placed nearly normally in the beam bd, figure 1, and provided with a horizontal axis and graduated arc. The amount (i) of rotation of the plate, corresponding to the vertical displacement of one central fringe in the telescope (i. e., the passage of the ring a, into b and then into c, in the spectrum, S, figure 3) was then found to be, if i is the angle of incidence,

	i	h	Δh
No fringes, c fig. 3	3.5°	0.0149 cm.	.....
One fringe, b fig. 3	5.0°	0.0214	0.0065 cm.
Two fringes, a fig. 3	6.5°	0.0281	0.0067

where h is the corresponding vertical displacement of the rays bd (see figure 2) and computed from (μ index, r angle of refraction)

$$h = d\,(\sin i - \cos i \tan r)$$

Thus the vertical displacement of rays corresponding to the vertical semiaxes of the central ellipse or one fringe is between 0.0065 to 0.0067 cm., i. e., a superior limit would be about 7×10^{-3} cm. Hence $h = N\ 0.007$ for N such central fringes is an excessive estimate.

The question is now suggested, in how far such an arrangement would fall short of being able to exhibit the drag of the ether in a rapidly rotating body, should such drag occur. In figure 1, let $\alpha\ \beta$ be a cylinder of glass with plane parallel ends, capable of rotating on the axle $\gamma\ \delta$. If l is the length of the cylinder μ its index of refraction, and and r the distance of either component ray (ac, bd) from the axis $\gamma\ \delta$, n the number of turns per second and V the velocity of light, we may write using the above estimate, N being the number of fringes displaced

$$h = \tfrac{1}{2} N \times 0.007 = 2\,\pi\,n\,r\,l\,\mu/V$$

since ac rises while bd falls. If $n = 200$, $r = 10$ cm., $l = 100$ cm, $V = 3\times10^{10}$, $\mu = 1.5$

$$N = 0.018, \text{ nearly.}$$

It would thus be necessary to estimate about 1/60 of a fringe, which is just beyond the limit of certainty even if n, r can be increased, and l multiplied by reflection. The device suggested is nevertheless of interest and deserves further consideration. In fact I have succeeded in increasing the sensitiveness about four times.

2. Displacement Interferometer. Jamin Type.—These considerations induced me to devote further study to the Jamin type of interferometer, figure 1. The mirrors M, N' were put on one pair of long slides (1.5 meters long) parallel to ac and the mirrors M' N on similar slides parallel to the former. In this way any distance ac or bd was available. The beams were about 16 cm. apart corresponding to a normal distance between the end mirrors (N N', M M') of about 12 cm. But these distances could also be increased from nearly zero (M and M' nearly contiguous) to about 20 cm. in view of the width of mirrors used. The angles at a, b, c, d were each about 45°, so that a rectangle of rays is in question.

The adjustment proved eventually to be quite simple by aid of a horizontal beam of sunlight with *weak* condenser lens and collimator. A thin wire is to be drawn across the slit. M and M' are first set for parallelism in the absence of N and N' by adjusting the images of the slit at the same level (horizontal) and equidistance on a distant wall. The mirrors N and N' are next put in place with the distances acd and abd about equal. The two images seen in the telescope at T (g removed) are then made to coincide both horizontally and vertically by adjusting N and N' and these are then slid by a small amount on their slides (direction ac) until the rays are coincident at d to the eye (light strips on the mirror coincide).

If now the grating g is inserted very, fine oblique fringes will usually be seen. These may be enlarged to a maximum by moving the micrometer controlling the displacement M' normal to itself. Somewhat coarser *horizontal* lines are thus obtained.

Finally the distant centers of the ellipses are brought into the center of the telescope by aid of the thick glass compensator (figure 2), (the equivalent air path of the other ray being correspondingly lengthened), by rotating the glass plate on a horizontal axis. The same result may be obtained by rotating N and N' on a horizontal axis, successively by small amounts, into parallelism with M and M'. But the compensator is more convenient.

The ellipses so obtained with common plate glass and a film grating at g were magnificent. A rough test of the diplacement interferometer was made by using the above plate glass of thickness $E = 0.434$ cm. where $z = E(\mu - 1) + 2B/\lambda^2 = 0.2428$ cm. In two experiments agreeing to within 10^{-4} cm., $2e = 0.3448$ cm. were the displacement obtained. Assuming that $\theta = 45°$, $2e \cos\theta = 0.2438$ cm. This agrees with z as nearly as may be expected unless θ is specifically measured.

3. Broad Slit Interferences. White Light. Residual Fringes.—Some

allusion has been made above to a type of interferences, totally different in size from the regular fringes, and seen in the broadened slit. These were finally isolated. They appear to best advantage in the absence of the spectroscope, in the broad *white* field of a very wide slit. The latter may be removed. They have the appearance when vertical of regular Young or Fresnellian fringes, very sharp and fine, achromatically black and white at the middle of the grid, colored and fainter outward. They are vertical when the enormously larger spectrum ellipses discussed above are centered. Like these they partake of displacement, here through the broad white slit image and this displacement is extremely sensitive in relation to the displacement of the opaque mirror M' (fig. 1) to which it is due. Thus a displacement of $\Delta N = 10^{-4}$ cm. of the latter, corresponded to a march of fringes through about .017 of the telescopic field of 3°, i.e. to 0.05°. This comprises two fringes or $\Delta N = 5 \times 10^{-5}$ cm. per fringe. Now these fringes are so fine, sharp and luminous that it should be possible on proper magnification to measure a few hundredths of this with an ocular micrometer. They supply the fine fiducial mark in displacement interferometry for which I have long been seeking. They appear in a white field, thus requiring no spectrum resolution, nor monochromiatc light. Moreover the source of light need not be intense.

I shall in referring to the new fringes use the term residual or achromatic fringes. Their theoretical breadth should be $\Delta N = \lambda / 2 \cos \theta$ agreeing substantially with the given estimate.

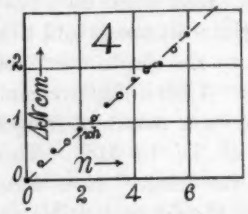
The displacement of fringes with ΔN at the mirror (when $n \lambda = \Delta N \cos \theta$) is so rapid that if they are lost it is difficult to find them, unless the centered large fringes in the spectroscope are first reëstablished. The latter are easily found. A removal of the prism grating gT, figure 1, and widening of the slit shows the achromatic fringes. The white pattern usually appears but once and is rarely present rhythmically as in the case of the next section for homogeneous light.

4. Wide Slit. Homogenous Light. Sodium Flame.—A clue to the nature of the residual fringes will be obtained when white light is replaced by homogeneous light. A strong large sodium flame near the mirror M, figure 1, suffices. The fringes now appear of the same size in yellow light and naturally spread over a much larger area of field. But on moving the mirror (ΔN increasing continually) forward very gradually, the homogeneous fringes alternately vanish and reappear, each time however enlarged in size but still straight, until at an intermediate position of symmetry enormous round ovals cover the yellow field. The fringes then diminish symmetrically in the same way. The

following data for the micrometer position corresponding to the clearest demarcations of yellow fringes are illustrative. At least six periods (n) are easily detected in each side of the ovals ($n = 0$) Thus,

n	6	5	4	3	2	1	0 etc.
$\Delta N \times 10^3$	0	49	90	127	171	214	243 cm. etc.

These intervals, since it is impossible to establish the maximums states of presence or absence of fringes quite sharply, are practically equidistant as the similar series in figure 4 indicates. Fringes in presence are here shown by black dots, the circles denote clear fields. Thus the mean period of reappearance is $\Delta N = 0.042$ cm.; or a path difference of $2 \Delta N \cos \theta = 0.059$ cm; or a shift of ray parallel to itself ($2 \Delta N \sin \theta = 0.059$ cm.) of the same amount.



The reason for this rhythm can only be the two wave lengths of the D_1 and D_2 lines of the sodium flame, originally detected in the colors of thin plates by Fizeau. Hence a relatively enormous shift of micrometer of nearly half a millimeter is equivalent to the wave length interval $\Delta \lambda = 6 \times 10^{-5}$ cm.; or $\Delta \lambda / \Delta N = 6 \times 10^{-5} / 42 \times 10^{-3} = 1.4 \times 10^{-6}$. Treating the case in terms of the interferences of thin plates and two wavelengths λ and $\lambda + d\lambda$

$$n\lambda = \text{constant, or } \frac{\Delta\lambda}{\lambda} = \frac{\Delta n}{n} = \frac{1}{n} \text{ for each period.}$$

Hence $$n\lambda = \frac{\lambda^2}{\Delta\lambda} = 2\Delta N \cos\theta \quad \text{or} \quad \Delta N = \lambda^2/2\Delta\lambda \cos\theta$$

since ($\theta = 45°$) approximately $\lambda = 60 \times 10^{-6}$ cm. $\Delta\lambda = 6 \times 10^{-5}$ cm.
$\cos\theta = 0.71$ $\Delta N = 0.041$ cm.,

agreeing as nearly as may be expected with the experimental datum. The apparatus thus serves incidentally for investigating such properties of spectrum lines as Michelson in particular has detected.

With white light the interference grid rarely reappears rhythmically nor does it correspond to the zero'th period of figure 4, i.e., to the ovals for sodium light. It is usually exactly of the size of some higher order, in yellow light, as at "*wh*" in fig. 4. It does not require such sharp horizontal and vertical coincidence of the superposed images, as the spectrum fringes.

In a flash of the arc, showing many sharp spectrum lines in all colors,

each of the lines gives evidence of the phenomenon; i.e., if the residual fringes are oblique, each such line is strongly helical in appearance.

Hence the equation for the residual fringes may be assumed to be

$$n\lambda = (e-e')\,[\mu \cos(r-\alpha) - \cos i]$$

when e and e' are the thicknesses of the two half silver plates, μ their index of refraction, i the angle of incidence, r the angle of refraction of an incident ray, and where α is the outstanding angle between the faces of the differential glass wedge, $e-e'$ thick at the ray in question. The possibility of throwing these fringes into any order of size, their small extent, sharpness and great abundance of light constitute their value for measurement.

THE PROTEINS OF THE PEANUT, ARACHIS HYPOGAEA

By Carl O. Johns and D. Breese Jones

PROTEIN INVESTIGATION LABORATORY, BUREAU OF CHEMISTRY, DEPARTMENT OF AGRICULTURE, WASHINGTON[1]

Communicated by R. Pearl, March 27, 1917

During the last ten years the culture of peanuts has increased rapidly in the United States. This increase is partly due to the fact that the boll weevil has made the growing of cotton unprofitable in various sections of the South and peanuts are now grown as a supplementary crop. Most of the peanuts thus produced are sold to the oil mills to be pressed for the oil which they contain. Shelled peanuts yield from 40 to 50% of oil. This edible oil compares favorably with olive oil and is used for culinary purposes and for making olemargarin. Press cake from shelled peanuts contains about 45% of protein (N x 6.25). This cake is ground to a meal which is rapidly finding favor as a cattle food. Peanut meal is now quoted at $35 per ton and peanut oil at $1.05 per gallon.

Previous to the present work, the only published experiments on the protein of the peanut seem to be those described by Ritthausen[2] in a paper which appeared in 1880. This author found that the proteins of the peanut consist chiefly of globulin and his analytical data led him to believe that only one globulin is present.

We have made fractional precipitations of the proteins extracted by sodium chloride solutions from oil-free peanut meal and have isolated two globulins, one of which is present only to a small extent. The globulin composing the greater part of the protein in the peanut is precipitated, when in 10% sodium chloride solution, by adding ammonium sulphate to 0.2 of saturation. To this globulin we have given the name *arachin*. After filtering off the arachin, the second globulin may be ob-

tained by dialysis or by saturating the filtrate with ammonium sulfate. This second globulin we have named *conarachin*.

Isolation of Arachin.—An extract was made by mixing 500 grams of peanut meal with 2.5 liters of a 10% aqueous solution of sodium chloride. This mixture was then run through a mill and the resulting thin liquid was filtered clear through paper pulp. To the filtrate, solid ammonium sulphate was added gradually until the solution became 0.2 saturated with this salt. A precipitate began to appear at 0.15 of saturation and increased rapidly until 0.2 of saturation was reached, when precipitation practically ceased and did not occur again until much more ammonium sulfate was added. On allowing the 0.2 saturated solution to stand overnight, the precipitate settled in a very compact form so that the supernatant liquid could be easily decanted. The precipitate was washed with a 10% sodium chloride solution containing ammonium sulphate to 0.2 of saturation. The residue was then redissolved in a small volume of 10% sodium chloride, and the resulting solution was filtered and dialyzed until chlorides were removed. In this manner the greater part of the globulin present in the meal was obtained as a white powder. This was suspended in alcohol for twenty-four hours and in anhydrous ether for another twenty-four hours. It was then filtered off and freed from ether in a vacuum desiccator and finally dried to constant weight at 110°C.

Isolation of Conarachin.—The filtrate from which arachin had been removed, and which was now 0.2 saturated with ammonium sulphate, was completely saturated by adding more ammonium sulphate. This treatment produced a small quantity of precipitate. This was redissolved in 10% sodium chloride and the filtered solution dialyzed until free from chlorides. The conarachin was then dried in the same manner as the arachin.

Isolation of an Albumin.—Beside arachin and conarachin sodium chloride solutions also extract from peanut meal a trace of albumin which coagulates at 65 to 70°C. Carbon and hydrogen determinations made on a small quantity of this albumin gave results which agree closely with the values obtained by Osborne[3] and his co-workers for the legumelins frequently found in the seeds of leguminous plants.

The difference in the composition of arachin and conarachin is shown by the following analytical results:

	ARACHIN *Per cent*	CONARACHIN *Per cent*
C	52.15	51.17
H	6.93	6.87
N	18.29	18.29
S	0.40	1.09
O	22.23	22.58

It will be seen that the greatest difference between these two globulins is in the percentage of sulphur, which is nearly three times as great in conarachin as in arachin. Another marked difference between these two proteins is shown by the figures representing the distribution of nitrogen as determined by the Hausmann method. The figures are as follows:

N	ARACHIN	CONARACHIN
Amide	2.03	2.07
Humin	0.22	0.22
Basic	4.96	6.55
Non-basic	11.07	9.40
Total	18.28	18.24

The high percentage of basic nitrogen in these proteins is most striking and, as far as we know, conarachin contains more basic nitrogen than any other seed globulin yet examined. For the sake of comparison, the percentages of basic nitrogen in proteins from some seeds commonly used for foods are also given below.[4]

PROTEIN	SOURCE	BASIC NITROGEN *Per cent*
Zein	Maize	0.49
Gliadin	Rye	0.91
Gliadin	Wheat	1.09
Phaseolin	Kidney bean	3.62
Vicilin	Pea	4.92
Arachin	Peanut	4.96
Legumin	Pea	5.11
Excelsin	Brazil nut	5.76
Edestin	Hemp seed	5.97
Globulin	Cocoanut	6.06
Conarachin	Peanut	6.55

Percentage of Basic Amino Acids in the Globulins of the Peanut.—Arachin and conarachin were hydrolyzed by boiling with 20% hydrochloric acid for twenty-four hours. The hydrolyzates were then analyzed by the Van Slyke method. The following results are corrected for the solubilities of the phosphotungstates of the bases:

	ARACHIN *Per cent*	CONARACHIN *Per cent*
Arginine	13.51	14.60
Histidine	1.88	1.83
Lysine	4.98	6.04
Cystine	0.85	1.07

The figures for cystine are undoubtedly too low as they represent only the cystine which escaped destruction during the hydrolysis of the proteins. Both proteins also gave a strong qualitative test for trypto-

phane. For the sake of comparison the percentages of lysine in the proteins of some common seeds and in muscle from some animals are also given in the following tables:

Lysine content of some vegetable proteins

PROTEIN	SOURCE	PER CENT
Zein	Maize	0.00[5]
Gliadin	Wheat	*1.21[6]
Legumin	Pea	4.29[7]
Phaseolin	Kidney bean	4.58[8]
Arachin	Peanut	*4.98
Conarachin	Peanut	*6.04

Lysine in muscle substance of different animals[9]

Scallops (*Pecten irradians*)	5.77
Halibut (*Hippoglossus vulgaris*)	7.45
Chicken	7.24
Ox	7.59

The figures marked by an asterisk were obtained by the Van Slyke method and, therefore, probably represent the maximum percentage of lysine obtainable. Those not so marked were obtained by Kossel's absolute method and may be somewhat too low. It is seen, however, that the percentages of lysine in arachin and conarachin of the peanut are relatively high and, indeed, approach the lysine content of muscle substance of different animals. It will also be noted that no lysine has been found in zein and that the maximum percentage of lysine obtained from gliadin is only 1.21%.

Osborne and Mendel[10] and other workers have shown that lysine is essential to the growth of animals. Nutrition experiments indicate[11] that the animal organism cannot synthesize lysine which must, therefore, be provided in suitable quantity in the food to insure normal growth. Since the muscle substance of animals contains about seven per cent of lysine, foods deficient in this essential amino acid should be supplemented by the addition of other foods which contain a high percentage of lysine. Diets of wheat and corn, both of which contain but little lysine, should therefore prove more efficient if supplemented by some food of high lysine content. Peanut meal appears to be well adapted to this purpose. From a nutritive standpoint it is one of our cheapest foods and seems to possess no objectionable properties. Animals fed on it thrive well and increase rapidly in weight.[12] It, therefore, seems probable that corn and wheat could be much better utilized and a considerable saving in the cost of feeding effected by supplementing these cereals with peanut meal.

[1] This article is published by permission of the Secretary of Agriculture. A part of the work of which this is a summary appeared in *J. Biol. Chem.*, 28, 1916, (77). The part relating to the determination of the basic amino acids in the proteins will appear in the May number of the same journal.

[2] Ritthausen, H., *Arch. ges. Physiol., Bonn*, 21, 1880, (81).

[3] Osborne, T. B., *Ergebn. Physiol.*, 10, 1910, (126).

[4] Osborne, T. B., *The Vegetable Proteins*, London, 1909, p. 57.

[5] Osborne, T. B., and Jones, D. B., *Amer. J. Physiol., Boston*, 26, 1910, (227).

[6] Osborne, T. B., Van Slyke, D. D., Leavenworth, C. S., and Vinograd, M., *J. Biol. Chem.*, 22, 1915, (259).

[7] Osborne, T. B., and Clapp, S. H., *Ibid.*, 3, 1907, (219).

[8] Osborne, T. B., *Ergebn. Physiol.*, 10, 1910, (116).

[9] Osborne, T. B., and Jones, D. B., *Amer. J. Physiol., Boston*, 24, 1909, (438).

[10] Osborne, T. B., and Mendel, L. B., *J. Biol. Chem.*, 22, 1914, (325).

[11] Hopkins F. G., *London, J. Chem. Soc.*, 109, 1916, (629).

[12] *U. S. Dept. Agric., Washington, Weekly News Letter*, 4, No. 22, 1916.

A DESIGN-SEQUENCE FROM NEW MEXICO

By A. V. Kidder

PHILLIPS ACADEMY, ANDOVER, MASS.

Communicated by W. H. Holmes, April 2, 1917

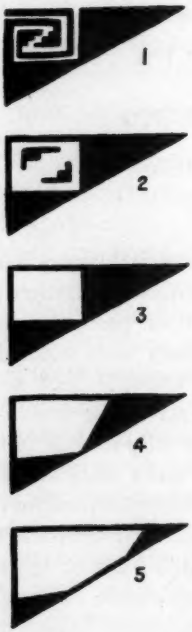
Much has been written on the development of geometrical decoration among primitive people, and many design-sequences have been arranged; the latter, however, have almost always been based on preconceived theoretical ideas, and the material for them has usually been selected from specimens whose relative ages have not been known. Such sequences cannot, therefore, be regarded as indicating surely the tendencies of design growth, for the specimens regarded as early may in fact have been late, and the development may thus have taken place in the opposite direction to the one postulated; or, again, the specimens may all have been of one period and may represent either contemporary variants of a single design-phase, or entirely unrelated parts of other unsuspected sequences. It has accordingly been impossible in most cases to do more than guess as to whether any given change in design has been from the natural to the conventional or vice versa; whether toward simplification or toward elaboration.

The only safe method for the working out of developments in decorative art is to build up one's sequences from chronologically sequent material, and so let one's theories form themselves from the sequences. In the case of aboriginal American art this ideal has been very hard to attain because of the scarcity of stratified sites and the corresponding difficulty of obtaining relatively datable specimens.

In the Rio Grande district of New Mexico, however, students have recently been recovering stratigraphical data which establish an orderly

succession of several pottery styles; so that almost any vessel may be placed in its proper chronological relation to any other. Close studies of the decoration of these vessels should enable us to recognize and tabulate enough true design-sequences to form the basis for a correct appreciation of the art tendencies in that area. Several such sequences are already becoming apparent; the accompanying incomplete example is given as an illustration.

While the five units in the series are from vessels from various sites, stratigraphical studies by Mr. Nelson at San Cristobal and by me at Pecos allow it to be stated positively that they are arranged in their proper chronological order. A description follows.



In the early black-on-white pottery a common design consists of a large triangle with two of its corners filled in with black; a pair of opposed stepped figures mounted on interlocking 'stalks' occupies the remaining rectangular space (fig. 1). In a primitive type of biscuitware which succeeds the black-on-white the same triangular element is often seen, and the two opposed stepped figures are also present but have lost their interlocking 'stalks' and hang suspended in the open space (fig. 2). In the biscuitware of a slightly later period the stepped elements drop out altogether, but the triangle holds to its original shape (fig. 3). In still later examples a progressive modification takes place in the cut-off and filled-in corners of the triangle; they become smaller and their two contiguous sides are no longer at right angles to each other (fig. 4). A final step is shown in figure 5; it is characteristic of the last type of biscuitware with which we are familiar.

This series represents, of course, only a short period in the life of this particular design; what phases it passed through in reaching the complicated form in which we first encounter it are as yet unknown; nor can we tell whether or not it had any later developments. In this short sequence we see: first, a progressive simplification due to the dropping out of elements (figs. 1, 2, 3); second, a modification in the shape of the remaining elements (figs. 4, 5). These data are, of course, too scanty for general conclusions, as they illustrate only one of many designs; they show, however, what interesting results may confidently be expected.

THE EQUILIBRIUM BETWEEN CARBON MONOXIDE, CARBON DIOXIDE, SULPHUR DIOXIDE, AND FREE SULPHUR

By John B. Ferguson

GEOPHYSICAL LABORATORY, CARNEGIE INSTITUTION OF WASHINGTON

Communicated by A. L. Day, April 4, 1917

The value of a study of the equilibrium between CO, Co_2, SO_2, and S_2 lies not in the reaction itself, important as this undoubtedly is both to the scientific and technical worlds, but rather in the fact that from such a study the free energy of sulphur dioxide, a quantity indispensable to a proper study of the chemistry of the sulphur compounds, may be directly obtained. That such an investigation has not heretofore been completed may be ascribed to the many difficulties which appear at the outset to block the way. The complex subsidiary reactions taking place at comparatively low temperatures are the source of many of these and would seem to have deterred Lewis and Lacey[1] from continuing their investigations in this direction. These reactions may be thus summarized:

$$\begin{aligned} CO + S &\rightleftharpoons COS \\ 2\,COS &\rightleftharpoons CO_2 + CS_2 \\ CS_2 &\rightleftharpoons CS + S \end{aligned}$$

They rendered the ordinary stream methods of investigation useless since by these methods samples could not be obtained which had not reacted after leaving the equilibrium chamber. A semi-stream method devised by the writer obviated this difficulty and samples so obtained from equilibrium mixtures at 1263° abs. showed no evidence of any such reaction taking place. Since the velocities of these reactions greatly exceed that of the main reaction, which goes according to the equation:

$$CO + \tfrac{1}{2}\,SO_2 \rightleftharpoons CO_2 + \tfrac{1}{4}\,S_2,$$

the absence of the products of the former clearly indicated that by this method cooling effects had been eliminated. Details of the method will be given in the final paper. By it a given gas mixture may be heated for a given time at a given temperature and a correct sample of the same then obtained for analysis. It has also the added merit that if the temperature be properly varied the equilibrium can be approached from either side.

A few of the results obtained in this way are presented in the following tables, K being defined by the equation:

$$K = \frac{P_{CO_2}^{\frac{1}{2}} \cdot P_{S_2}^{\frac{1}{4}}}{P_{CO} \cdot P_{SO_2}^{\frac{1}{2}}}$$

All of these with the exception of the measurements at 1458 were obtained from experiments in which platinum was present as a contact mass and the variations are probably due to analytical errors. The two measurements at 1458 were obtained from experiments in which a bare porcelain tube was used as a container and it is unlikely that equilibrium was reached in either case. An average of these two probably will be very near the correct value.

From these results the thermodynamical constant I for this reaction may be calculated by means of the equation:[2]

$$-RT\ln K = \Delta H_0 - \Delta\Gamma T\ln T - \tfrac{1}{2}\Delta\Gamma_1 T^2 - \tfrac{1}{6}\Delta\Gamma_2 T^3 + IT \qquad (1)$$

The additional data necessary has been well summarized by Lewis[3] and his co-workers with the exception of the specific heat of S_2 and and the value of ΔH_0 for the reaction $S_R + O_2 = SO_2$. The assumption that the former is the same as that of oxygen leads to the equation for the increase in heat capacity for the main reaction:

$$\Delta\Gamma = -(1.375 - 0.0028T + 0.000\,000\,937T^2)$$

The further assumption that Berthelot's[4,5] value of 69400 cal. for the heat of formation of sulphur dioxide from its elements at room temperatures gives for the reaction

$$\tfrac{1}{2}(S_R + O_2 = SO_2) \qquad \Delta H_0 = -34\,195 \text{ cal.}$$

and for the main reaction

$$CO + \tfrac{1}{2}SO_2 = CO_2 + \tfrac{1}{4}S_2 \qquad \Delta H_0 = -25\,915 \text{ cal.}$$

Substituting these values in equation (1) we have

$$-RT\ln K = -25\,915 + 1.375T\ln T - 0.0014T^2 + 0.000\,000\,155T^3 + IT$$

In table 3 will be found the values of I calculated by means of this equation from the results found in tables 1 and 2.

TABLE 1

EQUILIBRIUM APPROACHED FROM THE CO-SO_2 SIDE

TEMPERATURES		
Absolute	Centigrade	Log K
1271	998	1.79
1273	1000	1.73
1273	1000	1.77
1458	1185	1.13
1463	1190	1.19

TABLE 2

EQUILIBRIUM APPROACHED FROM THE CO_2-S_2 SIDE

TEMPERATURES		
Absolute	Centigrade	Log K
1277	1004	1.78
1458	1185	1.27
1463	1190	1.18

TABLE 3

TEMPERATURE	I CALCULATED
Absolute	
1271	3.88
1273	4.12
1273	3.94
1277	3.85
1458	3.97
1463	3.96
1463	4.00
Average value =	3.96

The agreement speaks not only for the results themselves, but justifies the assumption of $-$ 34195 cal. for ΔH_0 for the reaction, $\frac{1}{2}$ ($S_R + O_2 = SO_2$) and indicates the correctness of Berthelot's value for the heat of formation of sulphur dioxide. The free energy equations for the two reactions

$$CO + \tfrac{1}{2} SO_2 = = = CO_2 + \tfrac{1}{4} S_2 \text{ and}$$
$$S_R + O_2 = = = SO_2$$

may now safely be written.

The former will be

$$\Delta F_0 = -25\,915 + 1.375\,T \ln T - 0.0014T^2 + 0.000000155T^3 + 3.96T$$

and the latter

$$\Delta F_0 = -68\,391 + 3.62T \ln T - 0.0007\,T^2 + 0.000\,000\,317\,T^3 - 25.03T$$

Under standard conditions, therefore,

$$CO + \tfrac{1}{2} SO_2 = CO_2 + \tfrac{1}{4} S_2 \qquad \Delta F_{298} = -22\,529 \text{ cal.}$$
$$S_R + O_2 = SO_2 \qquad \Delta F_{298} = -69\,757 \text{ cal.}^7$$

The final paper will appear in the *Journal of the American Chemical Society*.

[1] Lewis, G. N. and Lacey N. *J. Amer. Chem. Soc., Easton, Pa.*, **37**, 1915, (1976)

[2] Lewis, G. N. *Ibid.*, **35**, 1913, (1).

[3] Lewis, G. N. and Randall, M. *Ibid.*, **34**, 1912; (1128), **36**, 1914, (2468); **37**, 1915, (465).

[4] *Ann. chim. phys., Paris*, (Ser. 5), **22**, 1881, (428).

[5] Berthelot's average value of 69260 includes results obtained from experiments in which the sulfur dioxide was determined by means of an alkaline solution. This procedure prob-

ably led to too low results and it is significant that those so obtained were lower than those obtained when iodometric methods were used. See 'The Iodometric Determination of Sulfur Dioxide and the Sulfites,' J. B. Ferguson, *J. Amer. Chem. Soc., Easton, Pa.*, 39, 1917, (364).

[6] Thomsen's value is 71080. (Thomsen, *Thermische Untersuchungen*, 2, p. 251)

[7] This value agrees with that derived from some preliminary investigations by M. Randall on sulfur and water (*Thesis, Mass. Inst. Tech., Boston*, 1912) and also with that obtained by Lewis and Bichowsky in a more complete investigation carried out at higher temperatures (private communication).

PHYSIOLOGICAL EFFECT ON GROWTH AND REPRODUCTION OF RATIONS BALANCED FROM RESTRICTED SOURCES

By E. B. Hart, E. V. McCollum, H. Steenbock, and G. C. Humphrey

DEPARTMENTS OF AGRICULTURAL CHEMISTRY AND ANIMAL HUSBANDRY, UNIVERSITY OF WISCONSIN, MADISON

Communicated by R. Pearl, March 29, 1917

Our early work[1] on the nutrition of herbivora with restricted rations demonstrated clearly the inadequacy of the accepted theory as to what constitutes a balanced or complete ration. Up to that time total protein—without reference to quality—energy, and ash materials were considered the essentials of a ration. The latter, however, occupied no position in the mathematical expression of the standards developed. The standards have been stated only in terms of total digestible protein and energy. It is, however, probably true that in a practical sense, and with the generally accepted knowledge of the quality of materials accumulated from a long and varied experience, that such standards have had and will continue to have very great value; but their limitations are also made evident by this earlier work and are emphasized by what we have since done. Within the past few years our knowledge[2] of the essentials of a ration have expanded and today we would consider a ration complete and efficient only when it contained protein of adequate quantity and quality, adequate energy, ash materials in proper quantity and proportion and two factors of unknown constitution (vitamines), designated from this laboratory[3] fat soluble A and water soluble B.

In addition to the above normal factors there may be introduced with natural food-stuffs the important factor of toxicity.[4] This can be wholly absent or so mild in its effects as to be entirely obscured when the other essentials of a ration are at an optimum adjustment; or with fair adjustment it may only reveal its effects when the ration is continued over a very long time and the animal involved in the extra strains of reproduction and milk secretion. This resistance to toxicity

is very materially increased through a proper adjustment of the normal factors of nutrition.

With this recognition of all the normal factors for adequate nutrition there must not simultaneously arise a desire for a mathematical expression of these factors in feeding standards. It is doubtful if this can ever be done, at least for certain of them. For example, the rôle of the mineral nutrients is so varied, including such widely separate functions as construction and control through antagonism as to make it seem futile to attempt an expression of absolute requirements when natural foods, with their diversity of mineral content, are involved. Even the recognition of differences in the quality of proteins and their relation to nutrition[5] will make it more difficult to continue expressing protein requirements in exact quantities than before the development of such knowledge; and what can be said of the quantitative requirements of fat soluble A and water soluble B and their supply in feeding materials?

All these developments of the last few years emphasize the need of a thorough study of the contributing nutritive factors of a *single* food stuff, and in the state of our present knowledge such information will be secured only by physiological tests, involving the animal in reproduction and milk secretion. A contributing factor by a natural food may at times be in the nature of toxicity and this may serve as a harmful and abnormal factor. As such knowledge develops and it becomes clear that this or that single food material will supply adequately the normal nutritive factors, not measurable by any quantitative chemical method, such as fat soluble A, water soluble B, or mineral nutrients, we will return with more confidence to the mathematical standard that only involves the energy and protein supply of that single food material. This confidence in the expressed quantities of energy and protein available in a food-stuff will rest upon the definite information that they become physiological effective only when they form part of a ration which carries one or a number of food-stuffs supplying adequately the other nutritive factors. With such an understanding the feeding standards developed on the energy-protein basis would continue to be theoretically sound and of very great practical value. As illustrative of our position, and taken from our own experience with wheat grain feeding we would feel reasonably safe if a wheat grain ration, based on protein and energy and to be fed continuously to a growing herbivorous animal, was built around alfalfa hay; less safe if built around corn stover, and fearful of disaster should the roughage used be wheat straw.

In our earlier experiments a 'balanced' ration from the wheat plant

gave fair growth, but complete failure in reproduction with heifers, while a 'balanced' ration from the corn plant was successful.

In our attempts to locate the trouble in the all wheat ration, wheat grain—wheat straw—we have fed rations made up of corn grain and wheat straw. Here the offspring were weak and often born dead. When to that same ration, however, a suitable salt mixture was added so that the ash content of the ration was like that of the all corn ration perfect offspring resulted. This would clearly indicate that one of the deficiencies of an all wheat plant ration was a proper salt mixture. When, however, the corn grain in the above ration was displaced by the wheat grain and the ration consisted of wheat grain—wheat straw and salts, disaster again resulted, which showed the presence of another disturbing factor in the wheat grain. Calves born by mothers upon this ration showed peculiar deflections of the head, inability to get up and suckle the mother, and in most cases have died within a few hours after birth.

These experiments indicate that in the all wheat plant ration there were two factors operative against normal nutrition, namely, a poor salt mixture and inherent toxicity of the wheat grain. When the wheat grain was coupled with corn stover we have sometimes met with success and sometimes with failure in the character of the offspring. With strong mothers it appears that the corn stover may become an 'antidote' and thereby furnish sufficient of all the normal factors of nutrition so as to enable the animal to reproduce normally.

The possibility of the toxicity being destroyed by heat was also investigated and baked wheat was fed with corn stover. This had no effect whatever in improving the wheat kernel.

In other cases the wheat grain-corn stover ration had butter fat added to it for the purpose of supplying plentifully the growth promoting—factor-fat soluble A—now known to be necessary for growth and supplied abundantly in butter fat. It was thought possible that the wheat grain-wheat straw ration was somewhat deficient in this material. Butter fat additions, however, did not uniformly improve the ration. We had a number of failures in reproduction, and also a number of successes with its use. This would again emphasize the probability of the presence of a toxic substance in the wheat grain.

When, however, the wheat grain was mixed with a legume hay, such as alfalfa, so that the latter formed but 20% of the ration, we have had perfect success in all cases in the production of normal offspring, at least for the first gestation. The improvement resulting from the use of the alfalfa must lie in introducing into the ration a better salt mix-

ture, perhaps a better protein mixture, and an abundance of growth promoting substances, all of which may contribute toward making it possible for the cell to destroy or resist the action of the toxic substance introduced. However, in the second gestation period on the same ration—wheat grain, wheat straw, alfalfa hay, the calves were weak, and in one case blind, but lived. This is extremely interesting as illustrating the cumulative effect of this toxicity.

Where corn stover was wholly substituted for the wheat straw we had a number of successes and also a number of failures in the first gestation period. Apparently this roughage was not as effective as an 'antidote' to the toxicity as the legume hay.

We had thought it possible in our earlier work that the acidity of the wheat ration was an important factor in the results recorded. It was true that the urine of the all-wheat plant fed animals showed a slight acidity to litmus due to a low intake of bases in the ration. If this were an important factor in our results then the successful corn ration might be disturbed with acids and give us results similar to the wheat ration. This however, we found not to be the case; for when to an all corn ration there were added mineral acids, such as sulphuric and phosphoric acids, in such proportions as to make the acidity of the urine of a degree similar to that of a wheat-wheat straw fed animal, the offspring were strong and normal in every respect. Even the addition of a high proportion of magnesium salts to a corn ration did not disturb in any way its power of producing normal offspring.

The results detailed above indicate clearly that wheat grain contains a toxic material, and later work has shown that this is very prominent in the embryo of the seed. When wheat embryo is imposed on corn stover so as to bring into the ration seven to eight times the amount of embryo that would be introduced when feeding whole wheat, the result is likely to be an early abortion. The calf is now dropped at six to eight months; this demonstrates that the increased mass of the toxic material produces this disturbance at a somewhat more rapid rate. This result was particularly apt to occur where no other grain was used with the embryo. With both corn meal and corn stover in the ration the detrimental effect of the wheat embryo was nullified, at least for a single gestation period.

It is an interesting fact that in the wheat milling industry the embryo passes into wheat bran in small amounts but in much greater quantities in wheat middlings. The wheat flour that is used for bread making has the least content of embryo of any of the wheat by-products.

In an attempt to obtain an anatomical picture of the condition re-

FIG. 1. CALF FROM COW 562

Wheat embryo 3 parts, corn starch 4 parts, corn stover 7 parts. The embryo of the wheat grain carries a considerable mass of toxicity. Massing this in the ration brought on early abortion with a gestation period of six to seven months. This ration was a so-called 'balanced' ration

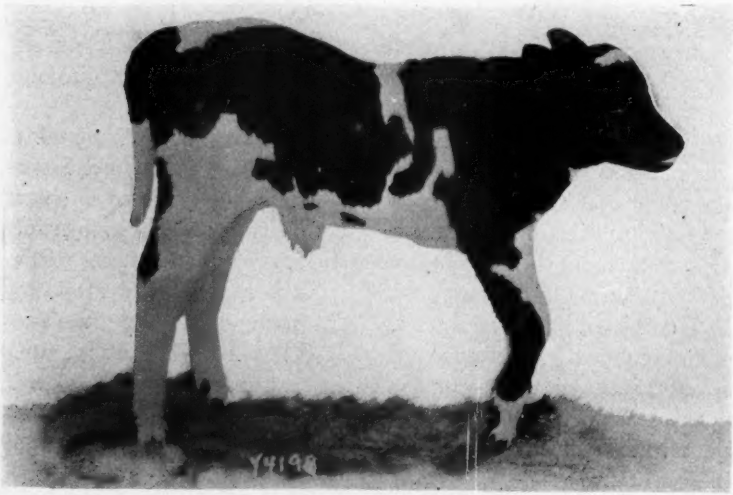


FIG. 2. CALF FROM COW 648

Second gestation on a ration of wheat grain 8 parts, wheat gluten 0.3 part, wheat straw 2.9 parts, alfalfa hay 2.9 parts. In the first gestation this cow produced a strong calf on this ration. In this second gestation period the calf was carried to full time, but was weak and was fed from a bottle; grew strong, but the front legs were weak and it stood for the first few days of its life on the first joints. *This calf was blind.* The mother remained in apparently good condition. This again illustrates the cumulative effect of the wheat toxicity.

sponsible for the physiological disturbances as already described, Dr. Bunting of the Medical School of the University, kindly consented to make a histological study of the tissues from a number of the abnormal calves. In general no striking lesions were revealed. Livers and kidneys showed some degeneration (hydropic) changes, but the nervous tissues gave the most evidence of the presence of an excessive amount of fluid—a condition of oedema. This histological picture was anal-

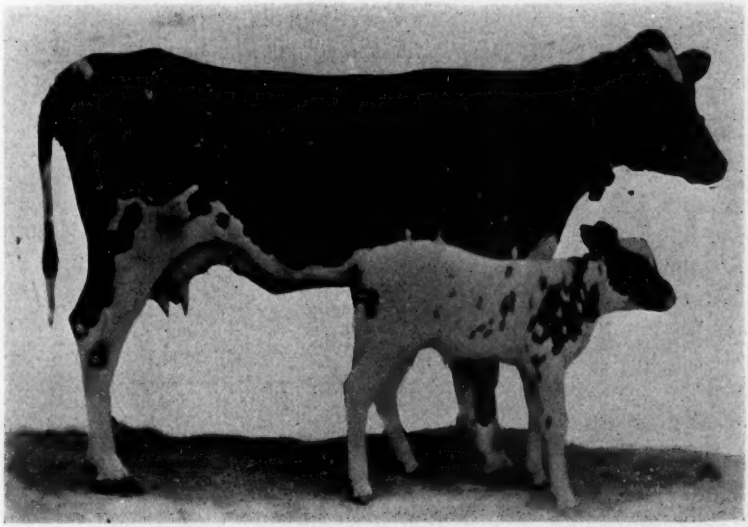


FIG. 3. COW 662 AND CALF

Successful reproduction in the presence of the embryo. A ration of corn meal 4 parts, corn starch 1 part, wheat embryo 2 parts, corn stover 7 parts. At least for the first gestation the 'antidotal' properties of corn meal and corn stover were sufficient to overcome the toxic effect of the wheat embryo. Without the corn meal and with only wheat embryo, starch, and corn stover in the ration reproduction would have been premature and the calf either dead or markedly undersize (see figure 1).

ogous to that of beri beri, the result of feeding polished rice, and it also simulated, if it was not identical, with that obtained from the spinal cord of pigs on certain rations as described in a previous publication.[4] The oedema was observed between the membranes covering the cord, around the blood vessels and around the nerve cells. In these instances the nerve cell and their nuclei were shrunken, the latter staining more intensely than normally. No abnomalities in medullation of the fibers of the cord as demonstrable by the Weigert stain were observed. While the observations did not point to anything especially characteristic it

is probable that the motor disturbances observed in the animals can be referred to the oedematous condition of the nervous tissues. The cause of beri beri is ascribed to the absence or deficiency of certain essential factors in the diet, particularly to water soluble B. In the case of excessive wheat feeding it would appear that the essential causal factor for disaster to growth and reproduction is a toxic substance which either interferes with the utilization of materials necessary for the full development of the nervous system of the animal or directly with the normal functioning of this tissue. This would account for the blindness observed in some of the heifers and also for the failure of muscular coordination apparent in the new born calves produced on rations of large whole wheat content.

It was also apparent that rations producing an early delivery of offspring would usually lead to a failure of the animal to remove properly the afterbirth, with its attending dangers of infection; and an overabundance of a material like wheat straw in a ration, owing to its low salt content, becomes an important factor in premature birth.

An observation in our experimental work of interest to veterinarians was the low resistance to other diseases of the mothers fed the wheat ration. In an outbreak of anthrax in the university herd the only losses to occur from this disease in our experimental herd were among the wheat grain fed animals.

The principle[6] laid down as to what factors must be present in a ration of natural origin in order that it becomes efficient for both growth and reproduction is well supported by these data. This principle postulates that there must be present efficient proteins, adequate energy, proper salt mixture, fat soluble A and water soluble B (vitamines) and an absence of toxicity or a toxicity of such mildness as to become inocuous in the presence of the other normal factors of nutrition. The presence of toxicity in the wheat kernel as the explanatory factor for these records rests not only upon the evidence secured with swine and rats but also on that presented here. *It is not a deficiency phenomenon.* A wheat grain, corn stover ration often failed, not only when used alone but when there was added to it the most likely limiting factor, fat soluble A, as butter fat.

The recognition of these normal factors of nutrition and the further recognition of the occurrence in apparently normal food-stuffs of substances of mild toxicity will be of immense advantage in arriving at an understanding of the oft reported troubles with farm animals which today are either not understood or their etiology wrongly assigned; and in the field of human nutrition the same principles will apply.

When a few years ago the corn crop of Nebraska failed to mature because of drought, but early rains had produced a bumper wheat crop it left many farmers with little to feed their breeding stock but wheat grain and certain roughages. In many cases where this was done the calves were born either dead or weak, with great financial losses to many breeders. No one would have suspected that the ration was a factor in these disasters, but it undoubtedly was the direct cause of the trouble.

When Dakota farmers, with their only roughage as wheat straw, try to build up an animal husbandry industry there is likely to arise trouble in reproduction with this class of animals unless other roughages with better salt mixtures are brought into the ration. We are informed that there is already much trouble with reproduction by cows in the Dakotas wherever much wheat straw is fed. Such facts as these must emphasize the importance of an understanding of all the factors of animal nutrition and in addition an understanding of all the factors contributed by any particular food-stuff. It should further emphasize how such studies can furnish the facts which will aid the animal feeder in avoiding the danger zones of his art. *We need more effort placed on the accumulation of information on the physiological behavior of feeding stuffs than on the attempts to bring out new mathematical expressions of feeding standards.*

These experiments further show the limitations of the theory of a 'balanced' ration as now expressed and indicate the very great importance of other factors besides protein and energy in the successful diet. It was indeed surprising to find that the common wheat kernel had a low toxicity; but such factors as toxicity, growth promoting substances of unknown nature, proper balance of salts, indicate how complex the problems of animal nutrition really are and how necessary it is that these factors be clearly exposed in order that we may place the various feeds in their proper category. We have pointed out how a material of low toxicity, such as the wheat kernel, may be used with success. A good roughage like a legume hay was an admirable 'antidote.' Even corn meal and a poorer roughage like corn stover served to offset the detrimental effects of a large mass of wheat embryo. This also illustrates how an adjustment of the normal factors of nutrition may conceal the presence of the detrimental factors.

It is important to keep constantly in mind that the disclosure of either a nutritive deficiency or the presence of an abnormal factor in a common natural food stuff should not necessarily condemn its use. It should, however, emphasize the need of combining it in the ration with

those other natural products which will either supply abundantly the deficiencies or act as an 'antidote' to any inherent toxicity.

[1] Hart, E. B., McCollum, E. V., Steenbock, H., and Humphrey, G. C., *Wisconsin Exp. Sta. Research Bull.* No. **17**, 1911.

[2] Stepp, W., *Zs. Biol., München*, **57**, 1912, (135) 62, 1913, (405); Hopkins, F. G., *J. Physiol.* **44**, 425, 1912; Funk, C., *Zs. Physiol. Chem.*, **88**, 1913; (352), **92**, 1914, (13); McCollum, E. V., and Davis, M., *J. Biol. Chem.*, **15**, 1913; (167), **23**, 1915, (231); Osborne, T. B. and Mendel, L. B. *Ibid.*, **15**, 1913, (311).

[3] McCollum, E. V., and Kennedy, C., *J. Biol. Chem.*, **24**, 1916, (491).

[4] Hart, E. B., and McCollum, E. V., *Ibid.*, **19**, 1914, (373); McCollum, E. V., and Simmonds, N., and Pitz, W., *Ibid.*, **25**, 1916, (105); Hart, E. B., Miller, W. C., and McCollum, E. V., *Ibid.*, **25**, 1916, (239).

[5] Hart, E. B., Miller, W. C., and McCollum, E. V., *Ibid.*, **25**, 1916, (239); McCollum E. V., Simmonds, N., and Pitz, W., *Ibid.*, **25**, 1916, (105).

WHAT DETERMINES THE DURATION OF LIFE IN METAZOA?

By Jacques Loeb and J. H. Northrop

LABORATORIES OF THE ROCKEFELLER INSTITUTE FOR MEDICAL RESEARCH, NEW YORK

Read before the Academy, April 16, 1917

1. It can be stated as a fact that most if not all organisms have a characteristic duration of life. To give extreme examples, many insects have a duration of life measured in weeks only, while the Californian sequoia has a duration of life of thousands of years, and in the human being the duration of life is proverbially three score and ten. The question arises: What determines this characteristic duration of life?

Bütschli was the first to point out that unicellular organisms have an unlimited duration of life and this idea has become very popular through Weismann. All recent researches support the correctness of this idea. As a consequence we are forced to the conclusion that natural death is a phenomenon found almost exclusively in organisms which are composed of different organs. The idea that natural death is connected with the compound character of organisms is supported by two facts; namely, first, the observation that a cutting will survive the whole plant, while the cutting if not separated would have died with the whole plant. By the method of cuttings the life of the individual plant can be prolonged apparently indefinitely.

The second fact is that if we take pains to transplant certain cells from an old organism successively to young organisms, these cells will outlive the original individual indefinitely—they are, in other words, immortal. The proof can only be furnished with the aid of marked cells and Leo Loeb selected for this purpose the cancer cell which is easily distinguishable from other cells by its rapid growth. He thus

showed that the cancer cell is apparently immortal and the same could possibly be shown for many other tissue cells if it were only possible to mark them and thus follow them individually through a series of successive graftings.

The experiments on hybridization also support the idea that natural death is due to some maladjustment in a compound organism. By fertilizing an egg with the sperm of another species we can bring about a shortening of the duration of life to an almost infinitely small fraction of the normal duration; and in some cases the opposite result may also be obtained. It depends whether in the hybrid the maladaptation of the parts is greater or smaller than in the pure breed. The problem then before the biologist is to find out the physicochemical character of this maladaptation which results in old age and death.

2. In certain organisms life is divided into two or more well defined morphological periods separated by an equally well defined process, the metamorphosis. Thus in the frog the metamorphosis from the tadpole stage consists in the growth of the legs and the absorption of the tail and gills. We know now through Gudernatsch that this metamorphosis can be brought about at any time by feeding the tadpole with thyroid, and it is possible that the natural duration of the tadpole stage is determined by the production of a certain quantity of a substance, possibly a specific constituent or product of the thyroid gland in the tadpole. This substance acts on many different organs in the body in a different way, causing the buds of the legs to grow and causing the tail and the gills to die by autolysis and by phagocytosis.

This suggests the possibility that the termination of the second stage in the frog's life, namely natural death, is also determined by the production in the body of one (or more) substances which bring about the termination of the second stage of life as definitely as the thyroid substance terminates the tadpole stage. It matters little whether we call such substances terminating one of the stages in life hormones or poisons.

3. In order to test the validity of such reasoning we have approached the problem by a method which one of us suggested in 1908[1] for this purpose, namely by ascertaining whether there is a temperature coefficient for the duration of life.

It is definitely established that a number of life phenomena have a temperature coefficient characteristic of chemical reactions, namely of about 2 for a difference of temperature of about 10°C.; although at the lower and upper temperature limit this coefficient changes more rapidly than it is usually found to change in purely chemical processes. This might be interpreted to mean that the order of magnitude of the

rate of such life phenomena and of chemical reactions is the same and that such life phenomena are due to definite chemical reactions, e.g., a reaction resulting in the formation of a hormone. Such a temperature coefficient was first observed by F. Lillie and Knowlton for the development of the egg of the frog and has since been found to exist generally.

If we could show that in a species with a definite metamorphosis there exists not only a definite temperature coefficient for the duration of life of the order of that of a chemical reaction, but that this coefficient is approximately identical with the temperature coefficient of the duration of the larval stage or stages, we should not have certainty but at least some probability that the duration of life is determined by causes similar to those which determine the duration of the larval stages. Our experiments were made on the fruit fly which has three definite stages, larval, pupa, and imago. We have already reported on some experiments in this direction[2] but our new experiments were made on forms which had been freed from all microorganisms. This was necessary on account of Metchnikoff's suggestion that poisons formed by intestinal microorganisms play an important rôle in limiting the duration of life.

Moreover, in our previous experiments only water or sugar solutions were offered to the flies and it was necessary to keep them on adequate food. It was found that on 2% glucose-agar the flies lived as long as on their natural food, yeast or yeast-agar. We preferred glucose-agar since it does not allow the larvae to hatch and we had to guard against this possibility since otherwise it would have been impossible to obtain correct figures for the death rate of the old flies. About 20 flies were kept in a large flask and about 8 to 10 different flasks with flies were used for the determination of life for any one temperature. The number of flies which died were counted each day and the duration of life for each temperature is the average for all the cultures kept at this temperature. The experiments were carried on in thermostats whose temperature was constant within one-tenth of a degree. The temperatures selected were 30°, 25°, 20°, 15°, and 10°. Table 1 gives the duration of the three stages for the different temperatures with the probable error.

These figures show, first, that the temperature coefficient for the larval stage, the pupa stage, and the life of the imago is of the order of 2 or above for 10°C., which is characteristic for both chemical reactions and life phenomena in general.

They show in addition, however, that the ratio of the duration of

the three stages is approximately constant for all temperatures as far as our experiments go. The ratios are given in table 2.

The values for the ratios at 15°, 20°, and 25° agree very well, while at 30° the value for the imago falls off; one of the cultures at 30° gave, however, the value of 0.22.

We may, therefore, say that as far as our present experiments go the ratio of the duration of life of the insect to the duration of the larval stage is approximately constant for all temperatures and that the same is true for the ratio of the larval to the pupa stage.

If it is permissible to consider the production of a hormone as the limiting factor for the duration of the larval stage we face the possibility that the production of a hormone (or a poison) may be also the

TABLE 1

DURATION OF THE THREE STAGES OF THE LIFE OF *Drosophila* IN DAYS

STAGES	10°	15°	20°	25°	30°	31.5°
Larva....	56.8 ±1.1	18.0 ±0.2	8.38 ±0.04	6.32 ±0.04	4.62 ±0.04	4.9 ±0.05
Pupa....	Does not hatch	13.5 ±0.2	6.1 ±0.1	4.22 ±0.03	3.43 ±0.04	
Imago[3]...			40.0 ±0.9	28.5 ±0.2	13.7 ±0.4	
Total length of life.....			54.5	39.0	21.7	

TABLE 2

RATIO OF DURATION OF THE THREE STAGES

STAGES	15°	20°	25°	30°
Larva: pupa.....	1.31 ±0.03	1.37 ±0.03	1.49 ±0.02	1.35 ±0.02
Larva: imago.....		0.21 ±0.2	0.22 ±0.1	0.33 ±0.1

limiting factor for the duration of the imago stage and the duration of a normal life in general.

On the basis of this assumption we can readily understand that by inadequate feeding of the larva the duration of the larval stage may be prolonged since the inadequate feeding may delay the formation of the hormone responsible for metamorphosis. It would be wrong to state that the duration of the larval stage is determined by the energy value of the food taken up by a normal larva since in the frog at least the larval period can apparently be prolonged indefinitely if certain hormones are lacking though the larva may grow considerably during this period. In the experiments on parthenogenetic frogs one of us has twice obtained a tadpole unable to metamorphose in a year or in a year and a half. One of these had grown beyond the normal tadpole

size. The latter was finally fed thyroid and began to metamorphose within a week. Both tadpoles were almost albinotic and from a recent paper by Allen it seems possible that in both larvae the hypophysis was abnormally developed or lacking. It is obvious that the production of a definite hormone and not the calory value of food is the limiting factor for the duration of the larval period.

4. *Conclusion.*—The experiments show that *Drosophila* has a temperature coefficient for the duration of life of the order of magnitude of that of a chemical reaction. Since the animals used in our experiments were absolutely free from microorganisms this influence of temperature on the duration of life cannot be attributed to bacterial poisons.

It was found, moreover, that the duration of the pupa stage is at each temperature proportional to the duration of the larval stage and that the same proportionality exists between the duration of the life of the insect to the larval stage, as far as our present experiments go. Since we know that the duration of the larval stage is determined by a specific hormone we are compelled to consider the possibility that the duration of life is also primarily determined by the formation of poisonous substances or a hormone in the body.

[1] Loeb, J., *Arch. ges. Physiol., Bonn*, **124**, 1908, (411); Moore, A. R., *Arch. Entw.-Mech., Leipzig*, **29**, 1910, (287). For a fuller discussion of the subject see Loeb, *The Organism as a Whole*, New York, 1916.

[2] Loeb, J., and Northrop, J. H., these PROCEEDINGS, **2**, 1916, (456).

[3] The experiments on the duration of life of the imago at 10° and 15° are not yet completed. From present indications it seems that for 15° the duration of life is in the neighborhood of ninety days, which agrees with the value expected according to the theory. At 10° the flies have been alive for ninety days and have not yet begun to die.

THE INTERRELATION BETWEEN DIET AND BODY CONDITION AND THE ENERGY PRODUCTION DURING MECHANICAL WORK IN THE DOG

By R. J. Anderson and Graham Lusk

PHYSIOLOGICAL LABORATORY, CORNELL UNIVERSITY MEDICAL COLLEGE, NEW YORK CITY

Read before the Academy, April 16, 1917

A dog weighing 8 kgm., in poor nutritive condition, was received into the laboratory. His basal metabolism, as measured during a period of absolute rest eighteen hours after partaking of an adequate standard diet, was 17.6 calories per hour. Traveling at the rate of 2.5 miles (4.0 km.) per hour he required 11.0 calories above the basal to move his body 1000 meters during the period beginning about eighteen hours after food ingestion, whereas 11.2 calories were required if 70 grams of

glucose had been administered immediately before the experiment began. These facts appear in the following table:

The interrelation between diet and body condition and the energy production during mechanical work in the dog

CONDITIONS	NUMBER OF EXPERIMENTS	WEIGHT IN KILOGRAMS	CALORIES OF METABOLISM	RESPIRATORY QUOTIENT	WORK IN DISTANCE TRAVELED PER HOUR		CALORIES ABOVE THE BASAL PER 1000 METERS	ENERGY IN KILOGRAMS TO MOVE 1 KGM. 1 METER
					Miles	Meters		
Basal	1	8.0	17.6	0.84				
Work, no food	1	8.3	60.7	0.78	2.48	3925	11.0	0.585
Work, glucose 70 grams	2	8.4	63.4	1.00	2.51	4170	11.2	0.566
Basal	4	9.1	17.2	0.85				
Work, no food	4	9.2	76.8	0.80	2.95	4760	12.4	0.578
Work + glucose, 70 grams	2	9.6	76.6	0.94	2.95	4750	12.5	0.550
Work + glucose, 100 grams	1	9.7	76.4	0.95	2.94	4740	12.5	0.550
Rest + glucose, 70 grams	2	9.3	20.7	1.05				
Work + meat, 750 grams	1	9.6	92.4	0.80	2.91	4700	16.0	0.708
Rest + meat, 750 grams	1	9.6	29.7	0.83				
Work + alanin, 20 grams	1	9.3	82.0	0.78	2.96	4780	13.6	0.620
Rest + alanin, 20 grams	1	9.4	21.1	0.84				
Fasting								
Day 3 + work		8.75	72.4	0.72	2.97	4800	11.7	0.569
4		8.6	16.1	0.73				
5 + work		8.55	70.1	0.73	2.94	4750	11.4	0.567
7		8.35	15.2	0.74				
8		8.10	14.2	0.71				
8 + work		8.10	70.6	0.72	3.11	5020	11.2	0.588
13		7.60	12.4	0.74				
13 + work		7.60	62.5	0.72	2.92	4710	10.6	0.595
15		7.45	13.0	0.73				

In a second series of experiments begun after an interval of six weeks, during which time the dog had added a kilogram to his body weight, it was found that when he moved at the rate of 2.95 miles (4.75 km.) per hour 12.4 calories were required to propel his body 1000 meters if the dog had been given no food in the morning, and 12.5 calories were required when 70 or even 100 grams of glucose had been administered. The rise in the respiratory quotient demonstrates the influx of glucose molecules for use in the cells for the production of power, and yet this influx caused no increase whatever in the heat production.

On the eighth day of fasting, when the body weight had fallen to 8.1

kgm. (the original weight of the dog), it required 11.2 calories to move the dog 1000 meters. On the thirteenth day of fasting, the basal heat production having fallen to 14.2 calories, it required 10.6 calories to move the dog, now weighing 7.6 kgm., a distance of 1000 meters.

A loss of body weight of 19% accomplished through fasting was accompanied by a fall in the basal metabolism of 28%, and an economy in the fuel necessary to move the body 1000 meters amounting to 15%.

This method of calculation, however, does not give an accurate picture of the interrelation between the nutritive condition of the dog and the amount of energy of metabolism necessary to accomplish a given amount of mechanical work, for it is obvious that to move a body weight of 9.2 kgm. through 1000 meters of distance would require a greater amount of energy than to move a body weight of 7.6 kgm. over the same distance. When the computation is based upon the energy equivalent in kilogrammeters required to move 1 kgm. of body substance 1 meter through space, it is found that an average of 0.580 kilogrammeter is required for that purpose with a maximum variation of $\pm 2.5\%$ no matter what is the nutritive condition of the animal. (The reduction in this value after giving glucose in solution to the dog is dependent on the fact that the weight of the glucose solution (± 280 grams) was reckoned as part of the weight of the dog. The carrying of this inert mass, however, did not appreciably increase the level of metabolism, as has already been set forth above.)

One may conclude, therefore, that *the accomplishment of a given amount of mechanical work is always at the expense of a given amount of energy, and that the amount of energy required for mechanical work is independent of the physical condition of the subject and independent of the quantity of carbohydrate food present in the gastrointestinal tract.*

No experiments have been made after giving fat but, since the authorities (Zuntz, Atwater and Benedict) are agreed upon the equal economy of iso-dynamic values of these two classes of food substances in the production of a given amount of mechanical work, it may be assumed that ingested fat acts like carbohydrate in metabolism when work is performed.

When meat is ingested the situation changes. Meat is a stimulant of the metabolism, as are several of its component amino-acids. The effect of work upon the heat production during the fifth and sixth hours after giving 750 grams of meat, and during the third and fourth hours after giving 20 grams of alanin, is summarized in the following table:

Chart indicating the influence of meat and of alanin upon the energy production during mechanical work in the dog

	Calories of metabolism per hour
Rest after meat, 750 grams	29.7
Basal	17.2
Difference	12.5
Work + meat, 750 grams	92.4
Work, no food	76.8
Difference	15.6
Rest + alanin, 20 grams	21.1
Basal	17.2
Difference	3.9
Work + alanin, 20 grams	82.0
Work, no food	76.8
Difference	5.2

It is apparent that meat acts as a stimulant to metabolism, raising not only the level of the basal metabolism but even increasing the quantity of additional energy required to move the dog, above the quantity to be expected were there a summation between the effect of protein stimulation and work to be accomplished. The same holds true of alanin, a simple cleavage product of meat which, in metabolism, is convertible into lactic or pyruvic acid, either of which may be transformed into glucose. Clear and sharp cut appears the distinction between the behavior of glucose itself and of alanin, which is convertible into glucose but whose intermediary acid products constitute a direct stimulus to metabolism, while the metabolites of glucose do not.

Summarizing, one may conclude:

1. Protein in the dietary is primarily for the repair of the tissues. It is not beneficial for the economical performance of work. In excess, it largely increases the heat production which a working organism is called on to eliminate.

2. One may reduce the basal requirement for energy by starvation, and this process may economize food in the case of those who do no mechanical work.

3. To accomplish a given amount of work a given amount of fuel energy is required, irrespective of the nutritive condition of the organism. This is of primary importance in the maintenance of armies or munition workers. Carbohydrate food fuel is utilized without loss.

4. Upon the capacity for heroism in the farmer will depend in the immediate future the security of the world.

REPORT OF THE ANNUAL MEETING

Prepared by the Home Secretary

The annual meeting of the Academy was held at the Smithsonian Institution in Washington, April 16, 17, and 18, 1917.

Seventy-three members were present as follows: Messrs. C. G. Abbot, Abel, Barnard, Becker, Bogert, Cannon, Cattell, Chittenden, W. B. Clark, F. W. Clarke, J. M. Clarke, Conklin, Coulter, Crew, Cross, Dall, Dana, Davenport, Davis, Day, Dewey, Donaldson, Fewkes, Flexner, Frost, Gomberg, Hague, Hale, E. H. Hall, Harper, Hayford, Hillebrand, Holmes, Howard, Howell, Iddings, Jennings, Lillie, Loeb, Lusk, Mall, Meltzer, Merriam, Merritt, Michelson, Millikan, Moore, Morley, E. L. Nichols, E. F. Nichols, A. A. Noyes, W. A. Noyes, H. F. Osborn, Pearl, Pickering, Pupin, Ransome, Remsen, Rosa, Schlesinger, Scott, Erwin F. Smith, Stieglitz, Van Vleck, Vaughan, Walcott, Webster, Welch, Wheeler, D. White, H. S. White, Wilson, R. W. Wood.

BUSINESS SESSIONS

The President announced the death since the Autumn Meeting of one foreign Associate: GASTON DARBOUX.

REPORTS FROM OFFICERS OF THE ACADEMY

The annual report of the President to Congress for 1916 was presented and distributed.

The President announced the appointment of the Local Committee as follows: CHARLES G. ABBOT, Chairman; WHITMAN CROSS, WILLIAM H. DALL, WILLIAM F. HILLEBRAND, CHARLES D. WALCOTT.

A Finance Committee for the PROCEEDINGS was also appointed, as follows: C. B. DAVENPORT, Chairman; M. T. BOGERT, W. B. CLARK, F. R. LILLIE, RAYMOND PEARL.

Other committee appointments, with date of expiration were as follows:

Program: C. G. ABBOT, Chairman, 1920; RAYMOND PEARL, 1920.

Henry Draper Fund: A. A. MICHELSON, to succeed himself, 1920.

J. Lawrence Smith Fund: WHITMAN CROSS, 1922.

Comstock Fund: A. G. WEBSTER, to succeed himself, 1920.

Marsh Fund: E. S. DANA, to succeed himself, 1920.

Murray Fund: G. H. PARKER, to succeed himself, 1920.

Marcellus Hartley Fund: THEOBALD SMITH and A. G. WEBSTER, to succeed themselves, 1920.

On Publication: E. B. ROSA.

The Home Secretary presented the following communication from Mr. Edwin B. Frost, resigning as a member of the Trustees of the Watson Fund:

DEAR MR. DAY: April 12, 1917.

Please present to the Council my resignation as a member of the Trustees of the Watson Fund. It is necessary for me to give up further service on this committee, but I am willing to continue as Chairman of the Bache Committee for another year.

Very truly yours, EDWIN B. FROST.

The resignation of Mr. Frost was accepted and Mr. A. O. LEUSCHNER was elected a member of the Trustees of the Watson Fund.

Mr. WILLIAM TRELEASE was appointed to represent the Academy at the inauguration of Walter Albert Jessup, as President of Iowa State University.

The report of the Home Secretary was presented as follows:

The President of the National Academy of Sciences.

SIR: I have the honor to present the following report on the publications and membership of the National Academy of Sciences for the year ending April 18, 1917.

The following publications have been issued and distributed: the *Memoirs of the National Academy of Sciences*, Volume 14, Memoir 1, entitled "Report on Researches on the Chemical and Mineralogical Composition of Meteorites, with Especial Reference to Their Minor Constituents," by George Perkins Merrill; Biographical Memoirs of Edward Singleton Holden, by W. W. Campbell; Theodore Nicholas Gill, by William Healey Dall; George William Hill, by Ernest W. Brown; and Alfred Marshall Mayer, by Alfred G. Mayer and Robert S. Woodward; also the Annual Report for 1915.

Two members have died since the last annual meeting: Cleveland Abbe, elected in 1879, died October 28, 1916; and Josiah Royce, elected in 1906, died September 14, 1916. Two foreign associates have also died: Sir William Ramsey, elected 1904, died July 24, 1916; and Gaston Darboux, elected in 1913, died March, 1917. There are 147 active members on the membership list, one honorary member and 37 foreign associates.

(Signed) ARTHUR L. DAY, *Home Secretary.*

The report of the Foreign Secretary was presented as follows:

On April 6, 1917, a cablegram was prepared by the Foreign Secretary of the Academy, with the approval of the five members of the Council:

"The entrance of the United States into the war unites our men of science with yours in a common cause. The National Academy of Sciences, acting through the National Research Council, which has been designated by President Wilson and the Council of National Defense to mobilize the research facilities of the country, would gladly co-operate in any scientific researches still underlying the solution of military or industrial problems.

HALE, *Foreign Secretary.*

The cablegram was sent to the Royal Society, London, England; to the Académie des Sciences, Paris, France; to the Accademia dei Lincei, Rome, Italy; and to the Académie des Sciences, Petrograd, Russia. (Signed) GEORGE E. HALE, *Foreign Secretary.*

The report of the Treasurer was presented in its printed form and approved:

REPORTS FROM COMMITTEES ON TRUST FUNDS

A report was received from the Directors of the Bache Fund, signed by Edwin B. Frost (Chairman), stating that since the annual meeting of the Academy in April, 1916, grants Nos. 196–201 (as announced in the PROCEEDINGS, vol. 2, p. 743) and Nos. 202–204 (as announced below, p. 398) had been made; and that reports on previous grants had been received as follows:

No. 186, J. VOÛTE, Royal Observatory, Cape of Good Hope. From a letter dated January 15, 1915, it appears that about 13,000 transits had then been observed for the purpose of determining stellar parallaxes. From a letter dated July 22, 1916: "The parallax work on the transit circle is nearly finished, but I have started a small series of about 125 stars on the astrographic refractor."

No. 187, H. H. LANE, University of Oklahoma. Preliminary report on "The Structure and Function in the Development of the Special Senses in Mammals," *Science, New York*, N. S., **43**, 1916, (179).

No. 188 and 196, H. W. NORRIS, Grinnell College. Research nearly ready for publication. Preliminary results on the cranial nerve of coecilians published in *Science, New York*, **43**, 1916, (182).

No. 189, E. J. WERBER, Yale University. Experiments aiming at the origin of monsters. The greater part of the results are published in *J. Exp. Zoöl., Philadelphia*, **21**, Nos. 3 and 4, 1916. Record of award closed.

No. 190, H. S. JENNINGS, Johns Hopkins University. For research in variation, heredity and evolution. Preliminary result published in *Genetics, Cambridge*, 1, 1916, (407–534).

No. 184 and 191, P. W. BRIDGMAN, Harvard University. To assist in the study of the effect of high pressures on the electrical resistance of metals. The results have been published in these PROCEEDINGS, 3, 1917, (10–12); *Boston, Proc. Amer. Acad. Arts, Sci.*, **52**, 1917, (571–646); and in a theoretical article soon to appear in the *Physical Review*. Record of award closed.

No. 192, J. P. IDDINGS, Brinklow, Md. For a microscopic study of volcanic rocks from the Dutch Indies, French Oceania and the Philippines. Preliminary results are published in these PROCEEDINGS, 2, 1916, (531). Research being continued under Grant 203.

No. 194, REGINALD A. DALY, Harvard University. For the construction of a deep sea thermograph. The vital part of the instrument is practically ready for testing, and it is hoped that the whole will be ready for work by May 1. The clock-work has been tested and shows capacity for taking 250 readings with one cast of the machine overboard. The manuscript descriptive of the instrument, by Dr. Harry Clark, the expert designer, to be illustrated with several full-page plates, is nearly completed. The necessary expenditure has considerably exceeded the appropriation.

No. 195, R. W. HEGNER, University of Michigan. To assist a research of "Differential Mitoses in the Germ Cell Cycle of Dineutes Nigrior." Preliminary publication in these PROCEEDINGS, 2, 1916, (356–360).

No. 197, GREGORY P. BAXTER, Harvard University. "The Preparation of Pure Anhydrous Zinc Chloride and its Analysis by Electrolysis" are under way and will probably be completed before the end of the college year.

No. 198, LOUIS T. MORE, University of Cincinnati. Preliminary results are published in the *Physical Review, Ithaca*, Ser. 2, **9**, 1917, (198–204), by J. S. Allen and L. M. Alexander, "On the Effect of Previous Filtering upon the Absorption of High Frequency X-Rays." The research continues.

No. 199, FRANKLIN P. REAGAN, Princeton University. The partial results are published in the *Anatomical Record*, Feb., 1917, under the title "Anterior Haematopoedis in Teleost Embryos Under Continual Observation," by F. P. Reagan, E. E. MacMorland, and Stuart Mudd.

During the year the Directors unanimously voted to cancel the rule heretofore effective for grants from the Bache Fund, which stated "No appropriation will be made to assist any investigation begun or conducted under any national or state government, either wholly or in part." The cash income balance of the fund on April 2, 1917, was $846.30; but there are outstanding grants, not yet paid, amounting to $2050. On three of these grants, amounting to $1600, the recipients of which live in foreign countries, it seems to be impossible to make payments until the end of the war.

A report was received from the Trustees of the Watson Fund, signed by Edwin B. Frost (Chairman), W. L. Elkins, and G. C. Comstock stating that grants Nos. 13–14 (as announced below, p. 398) were recommended, and that the available income of the Watson Fund in April 1, 1917, was $1213.65. Reports on previous grants were as follows:

No. 13, JOHN A. MILLER, Sproul Observatory, Swarthmore College. For measuring plates to determine stellar parallaxes, The money has been paid to an assistant, Miss Marie S. Bender, who has given all her energy to the measurement, and reduction of plates for determining parallaxes. She has measured 130 plates of 24 different series, and has computed the orientation factor and oriented 122 plates and has discussed eight different series by means of graphs. The continuance of the grant is requested.

No. 11, JOHN E. MELLISH. To undertake observations at the Yerkes Observatory. Used in 1915–16. Record of award closed.

No. 12, HERBERT C. WILSON, Carleton College, Northfield, Minn. For measuring the positions of asteroids on photographic plates. From a letter dated April 7, 1917: "We have measured all of our asteroid plates up to the beginning of this year, and all have been reduced. We are now going over the reductions thoroughly, checking them. . . . It will be a couple of months yet before we can get the matter ready for the press."

A report was received from the Committee on the Henry Draper Fund, signed by W. W. Campbell (Chairman), as follows:

The Committee recommends that a grant of $300 be made to Prof. Joel Stebbins, Director of the Observatory of the University of Illinois, in support of his investigations with sensitive photometers particularly the photo-electric cell photometer; the grant to be available on or before September 1, 1917. It is understood that this grant will be supplemented by the appropriation of a sum two or three times as great to be made by the University of Illinois, and that the total sum will constitute the salary of a research assistant for Professor Stebbins during the academic year 1917–18. It is expected that all of the assistant's time in the first year will be available for the researches in photometry and that after the first year the University authorities will assume the full responsibility for the assistant's salary. Professor Stebbins reports that improvements have been made in his photo-electric photometer. "A new quartz cell as compared with the cell used at Mount Hamilton (1915) gives twice the light effect, with the dark current five times smaller. It is therefore conservative to say that the sensibility has been doubled since 1915."

A report was received from the Committee on the J. Lawrence Smith Fund, signed by E. W. Morley (Chairman), stating that the income now available for grants is $677.13, and containing the following reports on previous grants:

No. 3, E. O. HOVEY, Curator in geology and paleontology, American Museum of Natural History, New York. For the study of certain meteorites. Dr. Hovey has been for some years out of the country and has not been reached by letters. He has suggested the repayment of the amount of this grant.

No. 4, C. C. TROWBRIDGE, Department of Physics, Columbia University, New York. To aid in study of luminous trains of meteors. During the last year good progress has been made in collecting photographs of drawings of meteor trains. One interesting result obtained is that the height of the zone of luminous trains agrees with the heights obtained in recent investigations on the auroral zone and is suggestive.

No. 6, S. A. MITCHELL, University of Virginia. To aid in securing observations of paths and radiants of meteors and in computing orbits where observations are sufficient. Good progress has been made in the work; and the committee are unanimous in recommending a further grant of $400.

Nos. 5 and 7, GEORGE P. MERRILL, of the U. S. National Museum. To aid in further studies of the occurrence of certain elements in meteorites. Upon the work for which he received grant No. 5 his final report has been made. This work is in progress.

A report was received from the Directors of the Wolcott Gibbs Fund, signed by C. L. Jackson (Chairman), Edgar F. Smith, and T. W. Richards, stating that the accumulated income of the Fund amounted to $356.11 on March

1, 1917, and that grants Nos. 7–8 (as announced below, p. 398) had been made. Reports from holders of previous grants are as follows:

Nos. 1 and 5, MARY E. HOLMES, Mt. Holyoke College. Her paper on the electrical deposition of copper is nearly ready for publication, and she has studied the electrical separation of cadmium from eight other metals.

No. 3, W. J. HALE, University of Michigan. Results published in a paper on "The formation of Cyclopentadienodihydropyridazines," *J. Amer. Chem. Soc.*, 1916, (2537–2545). Record of award closed.

No. 4, W. D. HARKINS, University of Chicago. Three papers are submitted: *a*. "The Free Energy of Dilution and the Freezing-Point Lowerings in Solutions of Some Salts of Various Types of Ionization and of Salt Mixtures." Harkins and R. E. Hall, *J. Amer. Chem. Soc.*, 38, (2658–2676). *b*. "The Freezing-Point Lowerings in Aqueous Solutions of Salts and Mixtures of Salts and of a Salt with a Non-electrolyte." Harkins and W. A. Roberts, *Ibid.*, (2676–2679). *c*. "Studies on the Cobalt-ammines. I. Various Ionization Types as determined by the Freezing-Point Lowerings in Aqueous Solution, Together with Conductance Measurements." Harkins, Hall and Roberts, *Ibid.*, (2643–2568).

No. 6. G. P. BAXTER, Harvard University. Studies, soon to be completed, on: *a*. Sources of error in the electrolytic determination of the atomic weight of cadmium, and analysis of cadmic sulphate. *b*. Gaseous impurities of silver and iodine. *c*. Relation between arsenious trioxide and iodine.

A report was received from the Committee on the Murray Fund, signed by W. H. Dall, stating that there was a cash income balance of $274.97 and that owing to conditions in Europe and the North Atlantic there was no recommendation and no report of progress to be made.

A report was received from the Committee on Biographical Memoirs, signed by C. B. Davenport, G. C. Comstock, A. G. Mayer, and A. L. Day, stating that each biographer had been circularized concerning the progress of the memoir in his charge. The biography of William Stimpson by A. G. Mayer is completed and that of F. A. P. Barnard is nearly ready. Biographies of all members who died more than fifteen years ago are thus accounted for. A circular letter was sent to all members of the Academy suggesting that each prepare at the end of each year an autobiographical record for the preceding year; a number of members have utilized this suggestion; and some have deposited biographical material with the Committee.

GENERAL BUSINESS

The Council reported the acceptance for the Academy of the gift of $8,000 made to the National Academy of Sciences by Miss Margaret Henderson Elliot in pursuance of her desire to carry out a testamentary provision in the will of her father, Daniel Giraud Elliot, which would have been operative under circumstances stated in the will and applied in accordance with the terms of the legacy as fully set forth in the will whereby a medal, to be known as the Daniel Giraud Elliot gold medal, together with an accompanying diploma and an unexpended balance of income for the year was to be awarded annually to the author of such paper, essay or other work upon some branch of zoology or paleontology published during the year as in the opinion of the judges, who shall be Henry Fairfield Osborn of New York, the Scientific Director of the American Museum of Natural History, and the Secretary of the Smithsonian Institution, shall be the most meritorious and worthy of honor.

Mr. William H. Welch presented the following letter, resigning the presidency of the Academy to take effect with the close of the present meeting, which was accepted with great regret:

National Academy of Sciences, April 16, 1917.

To the Members of the National Academy of Sciences.

GENTLEMEN: In accordance with the intention which I announced at our semi-annual meeting last November, I hereby tender my resignation of the office of President of the Academy to take effect at the close of the present annual meeting.

It is mainly the assumption of new and exacting duties and responsibilities connected with the organization and development of the School of Hygiene and Public Health recently established at the Johns Hopkins University which leads me to withdraw from a position which should receive much of the time and thought and energy of the incumbent.

It is a source of gratification that the Academy, while retaining its distinguished position as representative of those most eminent for their contributions to science in America, has widened in recent years its fields of activities and thereby become more useful and significant in the advancement of science in our country. It is to be hoped and expected that the Academy in its activities, influence and membership will be still further broadened and become increasingly serviceable and important in the promotion of knowledge and of the welfare of the nation.

I wish to renew the expression of my profound appreciation of the very high honor which was conferred upon me four years ago by election to the presidency of the Academy, as well as my appreciation of the continued loyalty and support and kindness of the members. I desire likewise to record my gratitude and indebtedness for the unfailing aid of the officers of the Academy, and especially of the Home Secretary and the Foreign Secretary, who have really carried the burden of the conduct of affairs. Faithfully yours,

WILLIAM H. WELCH.

The invitation of the Provost and Trustees of the University of Pennsylvania, to hold the Autumn Meeting in Philadelphia, was accepted.

The following resolutions were adopted:

WHEREAS, there is a great shortage in the supplies of platinum available for scientific and industrial purposes, and

WHEREAS, the shortage is in very great measure due to the extensive use of platinum for jewelry and other articles of luxury, therefore be it

Resolved, that the National Academy of Sciences, in this critical situation where all the resources of the Nation should be put to the use of those immediately active in the constructive, productive and defensive work of the country, appeal to the women and the men of America to refuse to purchase or accept as gifts jewelry and other articles made in whole or in part of platinum and thus to allow all the available supplies of the metal to be used where they can do the greatest good.

The Foreign Secretary presented the following communication from the Académie des Sciences at Paris received through the Ambassador from France to the United States:

AMBASSADE
DE LA REPUBLIQUE FRANÇAISE
AUX ETATS-UNIS

Washington le April 16, 1917.

MY DEAR MR. SECRETARY:

I am informed by my Government that our "Académie des Sciences" has received, from "the National Academy of Sciences," a friendly telegram by which they have been deeply touched.

I am instructed to forward to you their answer, the text of which is here enclosed.

I have the honor to be, dear Mr. Secretary,

Sincerely yours, JUSSERAND.
(Signed)

Mr. Hale,
Foreign Secretary
National Academy of Sciences,
Washington, D. C.

National Academy of Sciences, Washington, D. C. Paris, 13 avril, 1917.

L'Académie des Sciences de l'Institut de France est heureuse de saluer l'aide que votre noble pays apporte au nôtre, et à ses alliés dans leur lutte pour le droit et la liberté.

Elle vous remercie de votre offre, et sera heureuse de collaborer avec l'Académie Nationale des Sciences pour la solution des problèmes scientifiques interessant la defense nationale et l'industrie.

A. LACROIX,
EMILE PICARD,
Secrétaires Perpétuels.

The Foreign Secretary presented the following communication from the Royal Society, London, received through the Ambassador from Great Britain to the United States.

DR. GEORGE E. HALE, *Washington, D. C.*

The Royal Society heartily welcomes the offer of the National Academy to co-operate in scientific researches connected with the war, and will communciate by letter proposals for carrying this into effect. THOMSON, *President.*

ELECTION OF OFFICERS AND MEMBERS

President.—Mr. CHARLES DOOLITTLE WALCOTT was unanimously elected President for a term of six years to expire in 1923.

Vice-President.—Mr. A. A. MICHELSON was unanimously elected Vice-President for a term of six years to expire in 1923.

Treasurer.—Mr. WHITMAN CROSS was unanimously elected to succeed himself for a term of six years to expire in 1923.

Two Members of the Council.—Mr. A. A. NOYES and Mr. E. G. CONKLIN were elected to succeed themselves for terms of three years each to expire in 1920.

The following persons were elected as new members of the Academy.

HARVEY CUSHING, Surgeon, Harvard University, Cambridge, Mass.

ROBERT RIDGWAY, Ornithologist, United States National Museum, Washington, D. C.

WILLIS RODNEY WHITNEY, Chemist, General Electric Company, Schenectady, N. Y.

LIBERTY HYDE BAILEY, Horticulturalist, Cornell University, Ithaca, N. Y.

JOHN J. CARTY, Electrical Engineer, American Telegraph and Telephone Company, New York, N. Y.

WALTER SYDNEY ADAMS, Astronomer, Mount Wilson Solar Observatory of Carnegie Institution, Pasadena, Cal.

HENRY MARION HOWE, Metallurgist, Professor Emeritus, Columbia University, New York, N. Y.

EDWARD KASNER, Mathematician, Columbia University, New York, N. Y.

WALLACE C. SABINE, Physicist, Harvard University, Cambridge Mass.

EDWARD OSCAR ULRICH, Paleontologist, U. S. Geological Survey, Washington, D. C.

WILLIAM FREDERICK DURAND, Mechanical Engineer, Leland Stanford Junior University, Stanford University, Cal.

SAMUEL WESLEY STRATTON, Physicist, Bureau of Standards, Washington, D. C.
THEODORE LYMAN, Physicist, Harvard University, Cambridge, Mass.
EDWARD LEE THORNDIKE, Psychologist, Columbia University, New York, N. Y.
WILLIAM STEWART HALSTED, Surgeon, Johns Hopkins Medical School, Baltimore, Md.

SCIENTIFIC SESSIONS

Two public lectures on the WILLIAM ELLERY HALE Foundation were given on April 16 and 18 by EDWIN GRANT CONKLIN, of Princeton University, on Methods and Causes of Organic Evolution.

Four public scientific sessions were held on April 16 and 17 at which the following papers were presented:

J. P. IDDINGS and E. W. MORLEY: Report of progress in the study of igneous rocks from the East Indies and Islands of the South Pacific.

W. M. DAVIS: The Great Barrier Reef of Queensland, Australia (illustrated).

CHARLES D. WALCOTT: Searching for a doubtful geological zone in the Canadian Rockies (illustrated).

ARTHUR L. DAY: The rôle of the gases in volcanic activity (illustrated).

W. A. NOYES: A kinetic hypothesis to explain the function of electrons in the chemical combination of atoms.

A. A. MICHELSON (Draper Medalist, 1917): Some recent work in physics.

W. B. CANNON: Some considerations regarding the nature of thirst.

ERWIN F. SMITH: On Resemblances of Crown Gall to Cancer: A synopsis of work done in the United States Department of Agriculture.

R. J. ANDERSON and GRAHAM LUSK: The influence of diet upon the heat production during mechanical work in the dog.

JACQUES LOEB and J. H. NORTHROP: What determines the natural duration of life?

A. G. MAYER: Biographical memoir of William Stimpson. (By title.)

BENJAMIN BOSS: Biographical Memoir of Lewis Boss. (By title.)

SIMON FLEXNER: Mechanisms that defend the body from poliomyelitic infection, (a) external or extranervous, (b) internal or nervous.

T. S. GITHENS and S. J. MELTZER: The difference in the action of antipyretics according to the species of animals subjected to this action, the state of health of the animals, the height of their normal temperature and the substance employed.

CHARLES B. DAVENPORT: Heredity and juvenile promise of eminent naval men.

HENRY FAIRFIELD OSBORN: The causes of the evolution of proportions by mammals.

W. V. KING (introduced by L. O. Howard): Sporogony of malaria parasites. Photomicrographs of infected anopheles.

FRANK R. LILLIE: Sex-determination and sex-differentiation in mammals.

HERBERT J. SPINDEN (introduced by W. H. Holmes): Economic contributions of ancient America.

SYLVANUS G. MORLEY (introduced by J. W. Fewkes): The Naya hieroglyphic writing.

E. E. BARNARD: The star in Ophiuchus with great proper motion, total lunar eclipse of January 7, 1917; measures of the position of the nucleus of the great nebula of Andromeda (illustrated).

EDWIN B. FROST: Recent remarkable changes in a nebula (illustrated).

THE WORK OF THE NATIONAL RESEARCH COUNCIL, by GEORGE E. HALE, Chairman, National Research Council; CHARLES D. WALCOTT, Chairman, Military Committee; ROBERT ANDREWS MILLIKAN, Chairman, Physics Committee; MARSTON TAYLOR BOGERT, Chairman, Chemistry Committee; VICTOR CLARENCE VAUGHAN, Chairman, Committee on Medicine and Hygiene; followed by Discussion.

AWARD OF MEDALS

The following medals were awarded at the annual dinner on the evening of April 17, 1917, at the Raleigh Hotel:

The Henry Draper Medal, to A. A. Michelson of the University of Chicago for his numerous and important contributions to spectroscopy and astronomical physics.

The Medal for Eminence in the Application of Science to the Public Welfare, to Samuel Wesley Stratton for his services in introducing standards into the practice of technologists in the United States.

RESEARCH GRANTS FROM THE TRUST FUNDS OF THE ACADEMY

During the twelve months preceding the Annual Meeting of the Academy the following grants for the promotion of research, in addition to those listed in these PROCEEDINGS, **2**, 743, were made from the Trust funds of the Academy.

GRANTS FROM THE BACHE FUND

No. 202, W. C. ALLEE, Lake Forest College, Ill., $415. For an investigation of a possible correlation between the rate of carbon dioxide production and reversal in light reaction of certain Arthropods, especially May-fly nymphs.

No. 203, JOSEPH P. IDDINGS, Brinklow, Md., $500. For a continuance of the microscopical and chemical investigation of rocks collected by Mr. Iddings in Japan, Philippine Islands, Java, Borneo, Celebes, Sumatra, New Zealand, Tahiti, and the Leeward Islands, and the Marquesas.

No. 204, IRVING W. BAILEY, Bussey Institution, Harvard University, $300. To secure field data in regard to the effects of various tropical environments upon the growth forms of the Angiosperms and to secure material for a study of the effects of these environments upon the anatomical structure of the Angiosperms. (Expedition to Guatemala has been delayed.)

GRANTS FROM THE WATSON FUND

No. 14, JOHN A. MILLER, Sproul Observatory, Swarthmore College, $500. To measure plates for determining stellar parallaxes. (Supplementary to Grant No. 13.)

No. 15, HERBERT C. WILSON, Goodsell Observatory, $325. To determine the position and brightness of asteroids (chiefly those discovered by Watson) by the photographic method, together with a study of the brightness of some variable stars.

GRANTS FROM THE WOLCOTT GIBBS FUND

No. 7, W. D. HARKINS, University of Chicago, $200. For the purchase of an air-pump which will be of use in five researches either now in progress or to be undertaken in the near future.

No. 8, H. L. DATTA, Presidency College, Calcutta, India, £25. To provide organic substances for his researches of chlorination.

GRANT FROM THE J. LAWRENCE SMITH FUND

No. 8, S. A. MITCHELL, University of Virginia, $400. To continue his researches on the paths, radiants, and orbits of meteors. (Supplementary to Grant No. 6.)